AD-773 048

MINIMIZING DAMAGE TO REFINERIES FROM NUCLEAR ATTACK, NATURAL AND OTHER DISASTERS

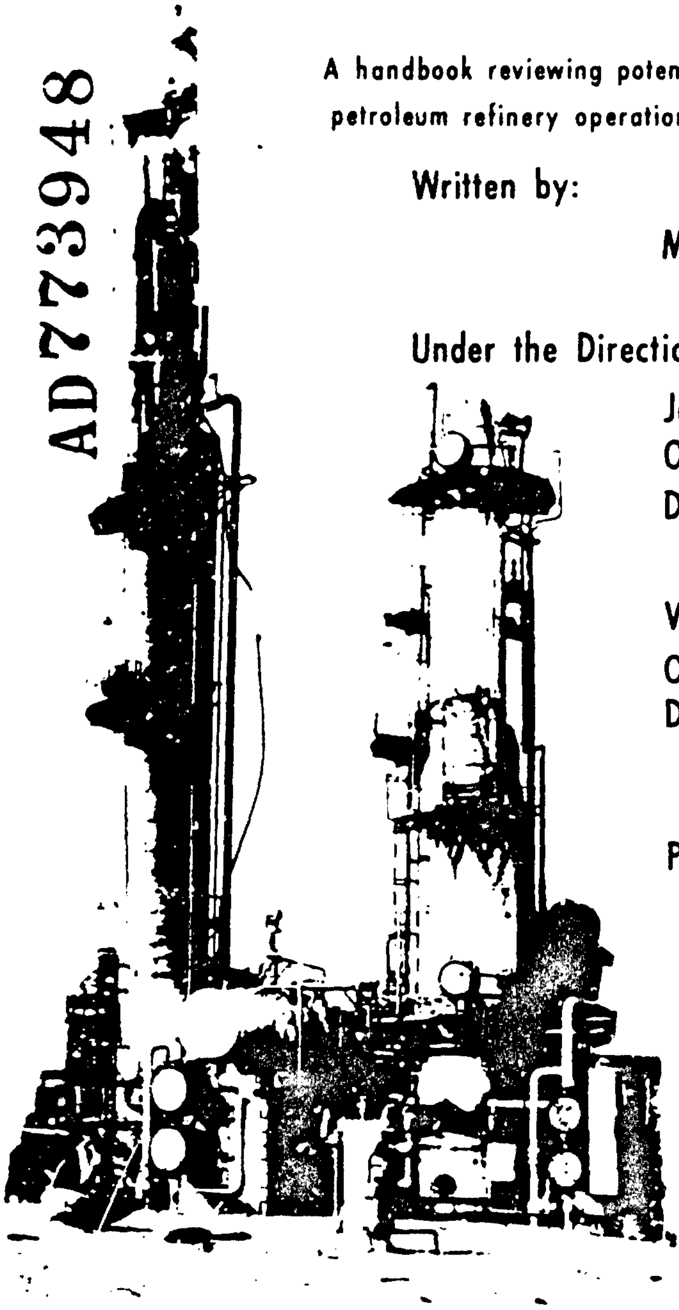
Office of Oil and Gas

prepared for
Department of the Army

February 1970

Minimizing Damage to Refineries

from Nuclear Attack, Natural and Other Disasters



A handbook reviewing potential hazards that could affect petroleum refinery operations in times of war and peace.

Written by:

Maynard M. Stephens

Under the Direction of

John Ricca, Deputy Director,
Office of Oil and Gas,
Department of the Interior

and

Virgil L. Couch, Ass't Nat.Director
Office of Civil Defense
Department of the Army

Prepared for:

The Office of Civil Defense,
Industrial Participation,
Department of the Army
Work Order: DAHC 20-68-C-0097

By:

The Office of Oil and Gas
The Department of the Interior

Feburary 1970

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, Secretary

HOLLIS M. DOLE, Assistant Secretary-
Mineral Resources

OFFICE OF OIL AND GAS

John Ricca, Acting Director

and

UNITED STATES DEPARTMENT OF THE ARMY

STANLEY R. RESOR, Secretary

OFFICE OF CIVIL DEFENSE

John E. Davis, National Director of Civil Defense

Virgil L. Couch, Ass't Nat. Director of Civil Defense
Industrial Participation

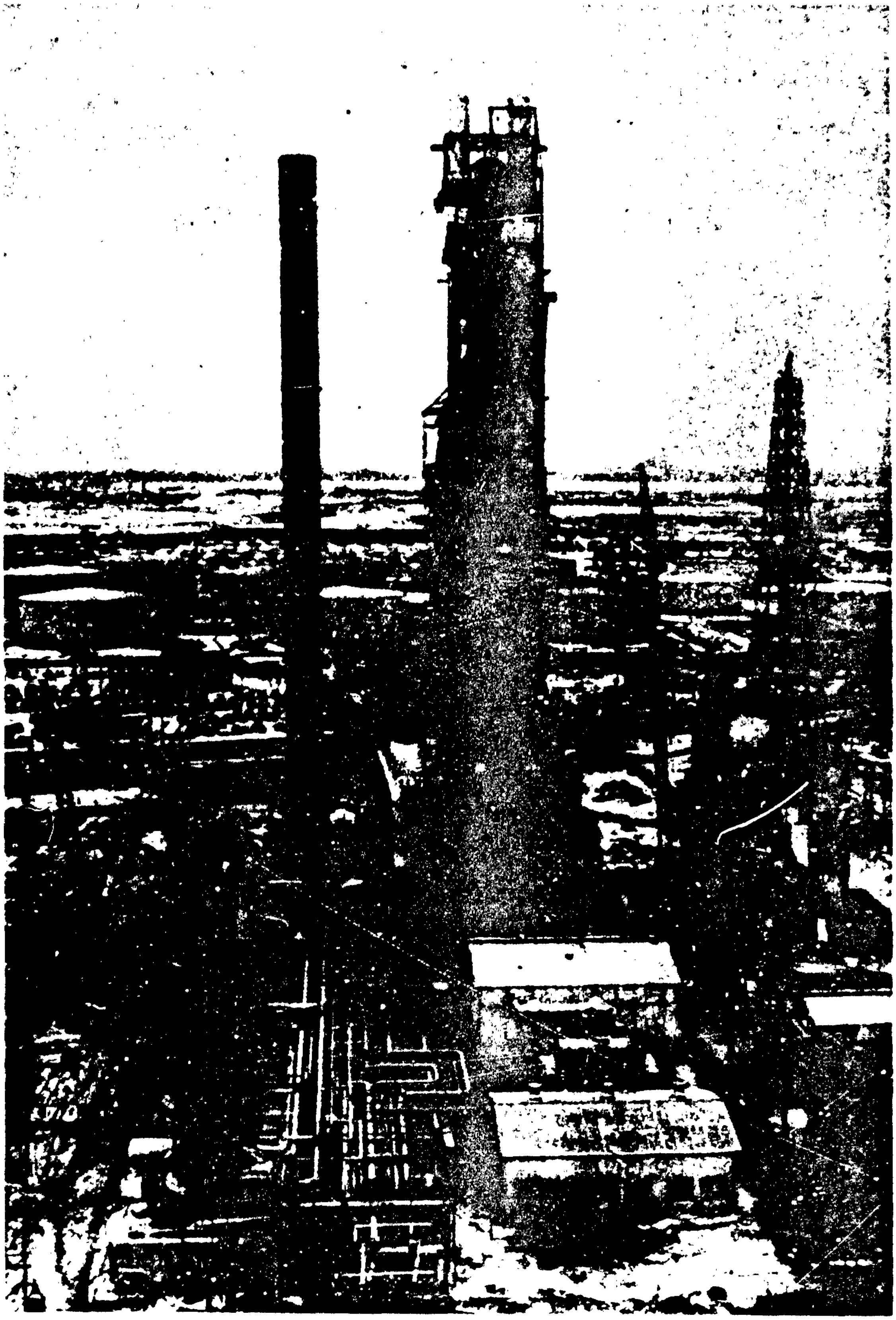


Figure 1. The Fluid Hydroformer Before the Explosion
(Source: American Oil Co.)

Figure 2. The Fluid Hydroformer After the Explosion

A study of the damage done by a detonation contributes much to the Knowledge of what possible damage can be done by a bomb blast.

(Source: American Oil Co.)

PREFACE

This manual is written for those of the petroleum refining industry who have management and technical responsibilities for the safety of personnel and for the continuous safe operation of their facilities. Much of the discussion also applies to industries using similar equipment.

The objective of this publication is to encourage refinery management to build added protection into its plants against all forms of disaster. It is realized, however, that economy of operation dictates that management give its main attention to the more prosaic duties of eliminating fires and explosions, minimizing potential damage caused by the ravages of severe natural phenomena, and reducing hazards related to the character of his products.

It is hoped that by protecting facilities against everyday hazards, that extra strength will be built into petroleum refineries so as to minimize the potential damage from any possible future major disaster. It is intended that the technical data presented here will give substantial aid to those responsible for emergency planning.

Since the petroleum industry including natural gas has the responsibility of supplying over 75% of the energy for our economy, the country must have petroleum processing facilities of adequate strength, and management ready to cope with all emergencies be they of natural origin or doings of mankind.

This manual is dedicated to this service.

John Ricca
Acting Director
Office of Oil and Gas

FOREWORD

The object of this publication is to review with refinery management and technical personnel:

1. The nature of the possible damage to installations and to people caused by hurricanes, tornadoes, fires, floods, or earthquakes, and the similarity of such forces to those created by nuclear weapons.
2. The probable extent and magnitude of the destruction resulting from a blast or natural disaster.
3. The research done by government and related agencies and industry which point out ways to strengthen a modern oil refinery to make it more damage and blast resistant within the realm of economic judgment.
4. Other problems to be expected in time of war.

A fair-sized nuclear explosion can occur within a few miles of a plant and still not put it out of operation unless critical parts of the refinery are too weakly constructed to withstand the shock, the strong wind, the intense heat, or the sudden blast (increased air pressure).

Some of the basic responsibilities related to the operation and the protection of a liquid fuel production facility such as a petroleum refinery, gasoline plant, petrochemical installation, or similar equipment against disasters and nuclear attack are:

1. The protection of management and operating personnel against injury from fallout or from building collapse due to high winds, strong blasts, intense heat, fire and floods.
2. The protection of vital records and control equipment, particularly where delicate instruments, computerized equipment, remote controls, and a mass of electrical wiring and connections are involved.
3. The improvement of rapid shutdown procedure so as to minimize serious damage to equipment.
4. The improvement of security procedures, fire protection and fire fighting methods.
5. The planning of recovery procedures, the removal of debris, the making of emergency repairs, and the restoration of the operation to normal.

The age of the equipment, the type of process, and the location of an installation have much to do with its risk susceptibility and the extent of the damage caused to it by greater than normal stresses. Although each plant will have its individual problems, there appears to be some problems common to each in a varying degree. Some of the weakest and most vulnerable areas or parts in a modern refinery are the unit control houses, the switchgear houses, the main transformer stations, the power house, the bolts securing structural framework of large refinery equipment to their foundations, the hydraulic and control lines, the supporting framework holding pipe and wiring, and the type of construction of water cooling equipment. The type and location of feed stocks and product storage are also problems. Many accidents are related to terminal areas.

It is good planning to have each unit control house not only strong enough to withstand a sizeable blast or natural disturbance so as to protect the equipment in it, but also by virtue of strength, design, and location provide a safe haven for the personnel in time of critical conditions. The extra strength built into such structures will also help protect them against hazards created by nuclear attack.

Stronger designs employed in the construction of water cooling towers will also reduce the danger of damaging this vital refinery area.

It is of great importance that plant personnel be trained as to what to expect in time of disaster and what to do about it. In case of a nuclear blast, most people will most likely survive, but many who are not schooled in survival techniques could perish needlessly.

One company executive stated in effect that the cost of strengthening refinery installations to be more resistant to high blast pressure and nuclear blast is simply one of the modern day necessary expenses of doing business. Such capital outlay is casualty insurance; one hopes never to collect on it, but when the occasion arises, such foresighted investment often makes the difference between doing business soon after the accident or suffering great losses to the corporation.

An executive might well ask himself, "If I knew that my plant would be subjected to an unusually strong blast soon, what should I do now to reduce the damage?"

It is intended that this publication shall give tangible help to those who may have the responsibility of keeping a refinery on stream in spite of adverse circumstances, by pointing out hazards that have loss potential.

Dr. Maynard M. Stephens
Industrial Specialist
Office of Oil and Gas

SUMMARY

Each day, approximately 15,000,000 barrels (42 gallons each) of crude oil and natural gas liquids are safely handled in this country and made into many products, most of which are highly combustible. The process used in refineries, the natural gasoline plants, and the petrochemical plants of the nation are relatively delicate in their nature and can be readily damaged. Yet, the safety record of these petroleum related industries is envied by management of many others that might generally be considered to be less hazardous.

As plants become larger and more complex the damage potential from an accident, from severe weather, from nuclear blast increases. Down time losses and increased risk susceptibility and their vulnerability to easy destruction are being aggravated either in part or collectively by the following:

1 - The push to increase existing capacity by the extention of onstream times, the restoration and use of older equipment, the enlargement of existing equipment and increasing the congestion within the plant.

2 - The concentrations of industry in relatively few centers.

3 - The concentrations of refinery capacity in areas having frequent hurricances, tornadoes, floods and earthquakes, and by or near tide water.

4 - The trend toward converting more and more of the crude into the liquid fuel range. The hydrogenation processes necessary to do this has introduced a highly explosive gas into everyday operations. The control of processes is becoming increasingly more critical and the equipment more sensitive to possible detonations.

5 - The full range of sensitivity to explosion of some processes and the effects of contamination may not be entirely understood.

6 - The almost complete dependence of industry on purchased electric power.

7 - The computerization of the industry, thus reducing personnel. The equipment not only is extremely sensitive, but also, there are fewer employees around to help in case of an emergency.

8 - The trend toward warehousing fewer supplies and less equipment, thus becoming more dependent on the inventory of other industries. Delivery time delays extend rebuilding times in case of an accident.

9 - The relatively weak construction of control houses, cooling equipment, and switch gear houses, the exposed piping, electric and hydraulic lines, and the use of foundation bolts of a size or alloy inadequate to withstand much stress other than that required for normal windloading.

10 - The building of larger storage tanks, the transportation of crude oil in supertankers, and the enlargement of port and terminal facilities to serve high rate unloading resulting in a concentration of highly combustible products and crude supply into a relatively small area.

Since petroleum products and natural gas are the source of over 75 percent of our nation's energy, plus being the suppliers of the feed stock for the vast petrochemical industry, our national economy cannot survive without a functioning petroleum refining industry–The continuous operation of the liquid fuel industry is essential to any war effort.

As added strength is built into our refining facilities to protect them better from the potential ravages of natural hazards, and to cope with the results of the in-plant explosions, fires, sabotage and equipment failures, the industry is also better preparing itself to operate in war time conditions. There were sound economic reasons for the location and size of the original facilities but growth demands and process changes often have created an increased vulnerability to hazards. Most plants have weaknesses that can be corrected to a financial advantage to its management.

Considering world tensions, it is important that management of all essential industry understand what will be required of them in time of war, to what destructive forces their personnel and facilities will be subjected, and what planning is required to be done now in order to better exist under war time conditions.

The Office of Civil Defense, The Office of Emergency Preparedness, the Office of Oil and Gas and other governmental agencies are extremely anxious to be of help to industry in their emergency planning and to make available the extensive literature written on the subject.

ACKNOWLEDGEMENTS

The material included in this manual was researched and gathered from many sources, most of which are acknowledged in the footnotes and bibliography.

The cooperation of industry is gratefully appreciated particularly those companies who devoted the time of their management and engineers to counsel with the author and made possible visits to their operations. These include Atlantic-Richfield, Sun Oil Co., Signal Oil Co., Standard Oil Co. of California, Standard Oil Co. of New Jersey, Humble Oil and Refining Co., American Petrofina, Inc., Humble Pipeline Co., and Esso Engineering and Research Co.

Conferences were held with members of the National Constructors Association collectively, and with engineers of member companies including Bechtel Corporation, the Ralph M. Parsons Co., Fluor Corp., and C. F. Braun and Co.

Research groups including Stanford Research Institute, Advance Research Inc., U.S. Naval Radiological Defense Laboratory, United Research Service, Checci and Co., members of the Office of Civil Defense, the National Petroleum Council and Environmental Science Services Administration (ESSA), of the Department of Commerce at times made suggestions as to sources of material and manual content.*

Warren Petroleum Corp, American Oil Co., Ethyl Corporation, Humble Oil and Refining Co., Caterpillar Corp., and others as indicated in the text, furnished photographs.

Conference with members of the National Fire Protection Association, American Insurance Corp., and Factory Insurance Co., were helpful in manuscript preparation as was the permission to use generously, papers presented to meetings of the American Institute of Chemical Engineers and American Society of Industrial Security and American Petroleum Institute.

This manual is the product of many people, each adding his experience and valuable suggestions. Appreciation is expressed for this advice and assistance to all who gave it.

---

*Environmental Science Services Administration in 1971 called National Weather Service of the National Oceanic and Atmospheric Administration. Early literature was published as ESSA.

TABLE OF CONTENTS

SECTION III

THE LIQUID FUELS INDUSTRY UNDER POST NUCLEAR BLAST CONDITIONS

INDEX TO ILLUSTRATIONS

Figure Number	Subject	Page Number

SECTION I

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER V

Figure Number	Subject	Page Number

INDEX TO TABLES

Section 1

Damage Susceptability of Refinery Installations

Chapter 1

INTRODUCTION

"There was a loud pop followed by a hissing noise and a boom; then the structure began to be enveloped in vapor. The operators inside the control room heard the noise, assessed the danger, and fled.... All buildings within the area over which the vapors spread sustained fire or explosion damage, and several buildings constructed of combustible materials were set on fire." This was an on-the-scene report by E. G. Warren[1] of a fire that suddenly enveloped a part of the Ethyl Corporation's No. 4 plant in Baton Rouge, Louisiana, Saturday July 31, 1965.

Refinery managers and members of their technical and operating staffs may have experienced a similar situation at one time in their careers even though refineries are by record very safe places in which to work. It is frequently stated that a refinery worker's greatest danger is during his travelling to and from work. Few industries excel the fine safety record of the companies operating in the petroleum refining and related fields. Still, where an industry is handling millions of barrels of highly combustible material each day, it may be anticipated that at some time and at some place the right combination of hydrocarbon, air, hydrogen or other chemicals, and heat will occur to cause a serious accident. It is the industry's knowledge of this potential hazard that keeps it constantly practicing safety and constantly training men in safety methods. Operators are constantly inspecting equipment for some signs of impending danger.

A few great explosions have occurred, some causing multimillion dollar damage and loss of life in spite of continued surveillance. The problem is further complicated by the fact that although much is known about the mechanics of detonations of large volumes of hydrogen impregnated with hydrocarbons, all is not completely understood.

Most normal explosions occur with some warning - a swish, a fire, a boom, or some other sign - all of which are familiar to a refinery worker. There is usually an instant to move to safety if such a place is provided.

Explosions and fires occur most frequently in the loading terminal. These are usually relatively small and do little damage because of their distance from large units, and well trained and well equipped specialists usually handle such problems efficiently. When explosions and fires do occur in the congested heart of a refinery, the problem becomes more difficult and more complex. But again, such occurrences are not uncommon, and most plants are well equipped to handle these situations when they occur.

Explosions

Two types of explosions are well known - one, those with all components in equilibrium chemically combining in an orderly fashion; and two, detonations, a turbulent condition with violence many times that of the first. When detonations occur, the magnitude of the resulting pressures can be devastating to any industrial operation. The force from such a blast is often comparable to that originating from a bomb.

With the general move in the industry toward the use of more and more hydrogen, oxygen and nitrogen in its various processes along with higher pressures - the danger of explosions of a detonation type has greatly increased.

Such explosions have occurred recently with greater frequency than in the years prior to 1954.[2] Few detonation type explosions are of record prior to that date. Some may not have been reported as such due to a lack of understanding of detonations. Jacobs[2] pointed out in 1959 that detonations were increasing in frequency in refineries since 1954, at an alarming rate. One of the greatest concerns of the industry is the avoidance of such disaster-causing detonations. Blast pressures created by these catastrophies within or near a plant are often in the range of those created by a nuclear weapon falling just a few miles away from the plant site. Peak pressures created by hydrocarbon detonations can be over twenty times that of a normal explosion created by explosive air/fuel mixtures at equilibrium, and the resultant shock wave delivers its blow at supersonic speeds. A more direct comparison of blast pressures and an analysis of their destructiveness will be more completely covered in later pages.

Men constantly work to prevent fires, explosions, ruptures, spills, equipment fatigue and corrosion failures, but, other problems confronting management result from the destructive forces created by nature. Uncontrollable tornadoes, hurricanes, earthquakes or floods can, under some conditions, give refinery personnel a taste of operational problems quite like those that can be expected from war.

The type of natural destructive force that might hit a plant will be determined usually by its geographical location. In the design of structures, architects and engineers should try to foresee and plan for the above-normal wind velocities of nature potential at their location, and where applicable, the potential effects of earthquakes and unstable soil conditions. There is a trend because of economic reasons not to over-design an installation. Safety factors may become less generous as cost of construction increases. This practice sometimes becomes false economy. And, should war come, those plants designed only for average conditions could be among the early and unnecessary casualties.

1 Warren, E. G. "Justification for Blast-Resistant Control Center Buildings" API Subcommittee on Facilities, Division of Refining, Los Angeles, California May 15, 1967

2 Jacobs, R. B. "Occurrence and Nature of Hydrocarbon Detonations"- API Division of Refining, Chicago, Ill. Nov. 9, 1959

Relationship of Nuclear Attack Preparedness and Everyday Refinery Problems

Combining the possible effects of fires, explosions, and detonations that might occur within a petroleum fuels manufacturing facility with the high wind velocities of the tornado or hurricane can result in destruction similar to that created by a nuclear blast with its heat, blast wave, and high wind velocity.

Each factor plays a separate role, and each has to be dealt with separately in design construction, depending upon the structure. As the engineers and technical staff seek out areas of weakness in their operation and take remedial action to strengthen the plant against natural hazards, and as they design to add protection against fires and blast damage that might result from their own operation, and as they inject innovations of design directed toward strength - they also make the facility more resistant to bomb blasts. Such construction practice in the long run could be economically justifiable.

There is much common ground between civil defense planning and modern day refinery design and operation. Foremost is the protection of life! Each plant must be as safe as it can be made! This should be a universally accepted management principle. But, havens of safety for personnel are essential in a modern installation, and there are not enough of these in many plants. Further, easily damaged sensitive equipment and critical areas must be properly protected from easy damage regardless of the cause.

In many cases the strongly constructed pressure vessels of a unit can withstand unusually high external stress created by either wind velocity or blast pressures. Their destruction often is due to failure of their supporting framework or the shearing of supporting bolts. When such happens, the entire tower or vessel collapses crushing all that is below it. Spacing considerations could have prevented some losses well known in our industrial history. A small fire in a congested area can be extremely serious. A multimillion dollar unit can also become severely damaged or be put out of service because of injured hydraulic lines or burned, unshielded electrical control wires. Cooling towers, storage tanks, some switch gear and other electrical installations and control houses particularly, appear to be relatively weak and sensitive spots in many refineries, gasoline plants, or in related petrochemical industries using similar equipment.

In case of nuclear blast, those plants where these and other weak points are corrected are the ones most likely to be either in operation after the occurrence or repairable in a short enough time to support our nation. In addition, those plants that provide areas of protection for their employees are the ones most likely to have workers survive and around when they are seriously needed.

It would be improper to imply that a war is imminent in the very near future, but if such occurred it is certain that modern weapons will be utilized to their fullest destructiveness. There are changes taking place on a world scale that affect our national security. Countries unfriendly to our system of private enterprise continue to create unrest and develop small limited war areas.

Objectives of the Manual

It is the purpose of this publication to call attention to the points of weakness in plants of the liquid fuel industry that are most apt to be damaged by a destructive force. The damage could ruin, or at least cause, a long "down time". There are several outstanding examples of extensive refinery damage. The various destructive forces have been the focus of attention by many people in research. Possibly the most useable and revealing information comes from the results of detailed investigation of accidents. While it is often difficult to entirely recreate the exact conditions leading up to an explosion or a serious fire, well trained investigators are usually able to reconstruct most of the events. Much of the data discussed in this book is based on such investigations.

By actually observing the resultant failure of structures, buildings, oil, gas and chemical lines, and other equipment, the force of the blast that caused the damage can be computed. Management and design engineers must use such information wisely in considering the possible recurrence of the conditions and in the design of buildings and equipment to withstand the destructive forces applied to them. Economics is always a consideration. The design men have the *know-how* to build an installation of almost any desirable strength. The problem is to protect without extreme overbuilding which might seriously deter an adequate return on the investment. The upgrading of the major elements of a modern refinery installation such as pressure vessels and towers is not usually necessary. These for the most part are quite strongly built because of the nature of their processes - but observed damage caused by in-plant experiences and those created in the past by nature do point out some weak links or areas in many plants. These easily damaged parts obviously need attention.

While the major powers seek to prevent a world enveloping conflict, still, commercial and opposing ideological interests are so intertwined that it may be possible to develop complete misunderstanding with little warning. President Nixon in his first news conference speaking of the fighting between small nations said, "The next confrontation could include a nuclear power." He later stated when referring to changes in the draft rulings, "If war comes in the future, it is more likely to be guerrilla or a nuclear exchange."- (a conventional war being unlikely).

Therefore, the problems of government also become the problems of the management of industry. Those plants most likely to be in operation after an outburst will be the ones built to withstand the damage. Much can be done in the construction of a plant to increase its security and resistance to weapons of war. The planners and designers of a new installation under construction or in its planning stage need to look at two new major threatening problems; one, the damaging effects of a bomb or missile from those who wish to destroy us from without, and two, the increased possibility of sabotage or guerrilla-like warfare from those who would destroy us from within.

Industrial security must always be kept strong enough to ward off possible sabotage and damage by enemies of our country. Where plant security is weak or lacking in plants

having easily damaged equipment, enemies and dissident groups will have little trouble achieving destructive objectives.

Our strength or our weaknesses could write our future history. We are no stronger than our industries, and each plant is no stronger than its weakest areas.

While this manual places emphasis on nuclear considerations, most of the discussion has direct bearing on present day operational problems. Those who build well now for immediate needs, build well for possible future needs.

Chapter II

HAZARDS PLAGUING MANAGEMENT

The numerous problems facing management of the liquid fuels industry increase daily in number and intensity. While some few old problems recur, as new construction continues and as capacity of existing equipment is increased new challenges will almost surely appear.

The increased cost of money, labor, and materials have put a profit squeeze on industry. It is fundamental that the dollar sign must always be in view of management if an industry is to flourish economically. It is recognized that there develops a continuing conflict between what can be done in plant construction and what should be done. Many plants are designed for normal conditions assuming that the unexpected will never occur. It may be difficult in some instances for management to justify extra construction costs strictly for the sake of protecting the plant against nuclear threats occurring at some undetermined time in the future. However, justification for such expense has been recognized by many companies. Others are injecting a risk factor into their operations that could be reduced if strenuous effort were made to eliminate or strengthen the weakest parts of their refinery installations now responsible for much of the refinery's extreme vulnerability. Thus, while some companies build in the extra protection needed to cope with most everyday hazards, some of which can be predicted - others continue to operate with the belief that "it can't happen here".

Table 1 lists many of the problems facing management. (See Table 1). The order and frequency of occurrence will vary depending on the location of the industry. Some plants will have added problems peculiar to that installation. The problems that are most pressing on a refinery manager's mind would be those related to in-plant problems of operation. These he is alert to avoid. Operational interruptions created by others, such as power failure, strikes, and fires of neighbors, or by phenomenon of weather, although they are of great concern, are not within the manager's control. A plant must be ready for all situations regardless of their origin. And, the safety of personnel is paramount.

Table 1. Hazards Effecting Industrial Operations

Hazards Related to Industrial Origin

I. Hazards Within Plant Origin
  A. Fires
    1. Explosions
    2. Burning products
  B. Spills
    1. Leakage
      a. Tank failure
      b. Line breakage
      c. Chemical le[illegible]
    2. Overflow of ta[illegible]
    3. Loss of fluids through open valves
  C. Power plant failure
    1. Loss of steam
    2. Loss of electricity
    3. Loss of hydraulic and pneumatic systems
      a. Failure of automatic equipment and instruments
  D. Interruption of cooling water supply
  E. Excessive exposure to radioactive materials
  F. Structural failure
  G. Communication failures
  H. Security failure
  I. Losses due to work interruptions
    1. Organized work stoppage
    2. Individual actions
      a. Excessive sickness
      b. Excessive absenteeism
II. Hazards Outside of Plant Origin
  A. Utility and supply failures
    1. Electrical failure
    2. Fuel (gas, coal, or oil) supply failure
    3. Water supply failure
    4. Interruption of supply
      a. Chemical and feed stock shortage
      b. Equipment and material shortages
  B. Fires and explosions from nearby areas
    1. From ships at dock and terminal areas
    2. From railroad tank cars and trucks
    3. From nearby plants
    4. From housing developments
  C. Transportation failure
    1. Pipeline breakage
    2. Interrupted shipping
  D. Damage from falling objects
    1. Crashed aircraft
    2. Misdirected missiles
    3. Fragments from nearby explosions
  E. Work stoppages
    1. Strikes at suppliers' plants
    2. Strikes of transportation
  F. Communication failures

Hazards Related to Natural Origin

I. Hazards Related to Weather (Meteorological)
  A. High winds
    1. Hurricanes, typhoons and tropical storms
    2. Tornadoes (called cyclones still in some areas)
      a. On land
      b. On water
        (1) Waterspouts

Table 1. (Continued)

3. Thunderstorms
   a. Sudden rainfall
   b. Hail
   c. Lightning
4. Gales

B. High water
1. Heavy rainfall
   a. Excessive moisture
   b. Floods
      (1) Sudden thaw of ice and snow
   c. Mud
2. Excessive tides and waves causing floods
   a. Storm tides
   b. Tidal waves
      (1) Taunamis (tidal wave)
   c. Seiches (on Great Lakes and others)

C. Snow and ice
1. Heavy snowfall
   a. Blizzards
2. Sudden freezes
   a. Sudden thaws
3. Freezing rains (once called sleet)
   a. Ice storms
4. Icebergs

D. Drought
1. Reduced water supply
2. Fires
3. Dust storms

II. Hazards Related to Earth Movement (Geological)

A. Earthquakes
1. High intensity
2. Low to moderate intensity

B. Land subsidence

C. Avalanches and landslides

D. Volcanoes
1. Lava flow
2. Fires
3. Ashes and gases

E. Tidal waves (See high water)

III. Hazards Related to Outer Space (Astronomical)

A. Excessive exposure to sunlight and cosmic rays

B. Falling meteorites

Hazards Related to Civil Origin

I. General Strikes

II. Civil Disobedience

A. Riots

B. Arson

C. Sabotage

III. Failure of Public Safety Facilities

A. Breakdown of civic fire protection

B. Breakdown of police protection

Hazards Related to Warfare

I. Insurrection

A. Hazards related to civic origin

II. Espionage

A. Failure of Security Measures

III. Conventional warfare

A. Direct shelling

B. Rockets and missiles

C. Bomb drops

D. Chemical warfare
1. Use of gases
2. Use of incendiaries

E. Biological warfare

IV. Nuclear Warfare

A. Direct shelling

B. Rockets and missiles

C. Bomb drops

The Push to Capacity

At present time there are economic pressures to use refinery equipment to its capacity and to extend "on stream" time. Such a general move could be expected to increase the problems of management and to increase vulnerability because of equipment failure. Some plants have "on stream" inspection capability which add to its safety.

Since 1964, the almost two million barrels of excess crude refining capacity of our refineries has continued to shrink. This story is dramatically told by D. H. Stormont.[3] By 1969, because of gains of demand, much of this excess was absorbed. (See Figure 3). Demands for motor fuel as well as turbine fuel outstripped the pace of new construction. Most refineries have pushed to the utmost to meet market demands, the turbine fuels making the biggest percentage gains. About 250,000 barrels per day more jet fuel were being produced by the beginning of 1969 that were produced in 1965 but 1970 demand fell below that of 1969. The production of motor fuels, of course, gained appreciably also.

Hydrocracking along with coking are the two processes (See Figure 4) that contributed the greatest to the increased volume of liquid fuels. While catalytic cracking processes are popular with refiners, zeolitic-type catalysts have gained in use. In order to increase gasoline yields from a barrel of crude, many refiners have employed the use of sieve catalysts and existing plants rather than to build new plants, Mr. Stormont reports. It is easy to see how a drive for added domestic petroleum refining capacity could create problems increasing with the age of the facilities. (See Figures 5 and 6).

Extra downstream processing was added to older facilities to help increase refining capacity that was lagging in spite of the building of new crude capacity in the past years. Delayed cokers and fluid units are being built to further the trend toward meeting the demand for light fuels. This rush

3 Stormont, D. H. "U.S. Refineries on Big New Capacity-Building Binge" Oil and Gas Journal, Jan. 27, 1969 p. 39

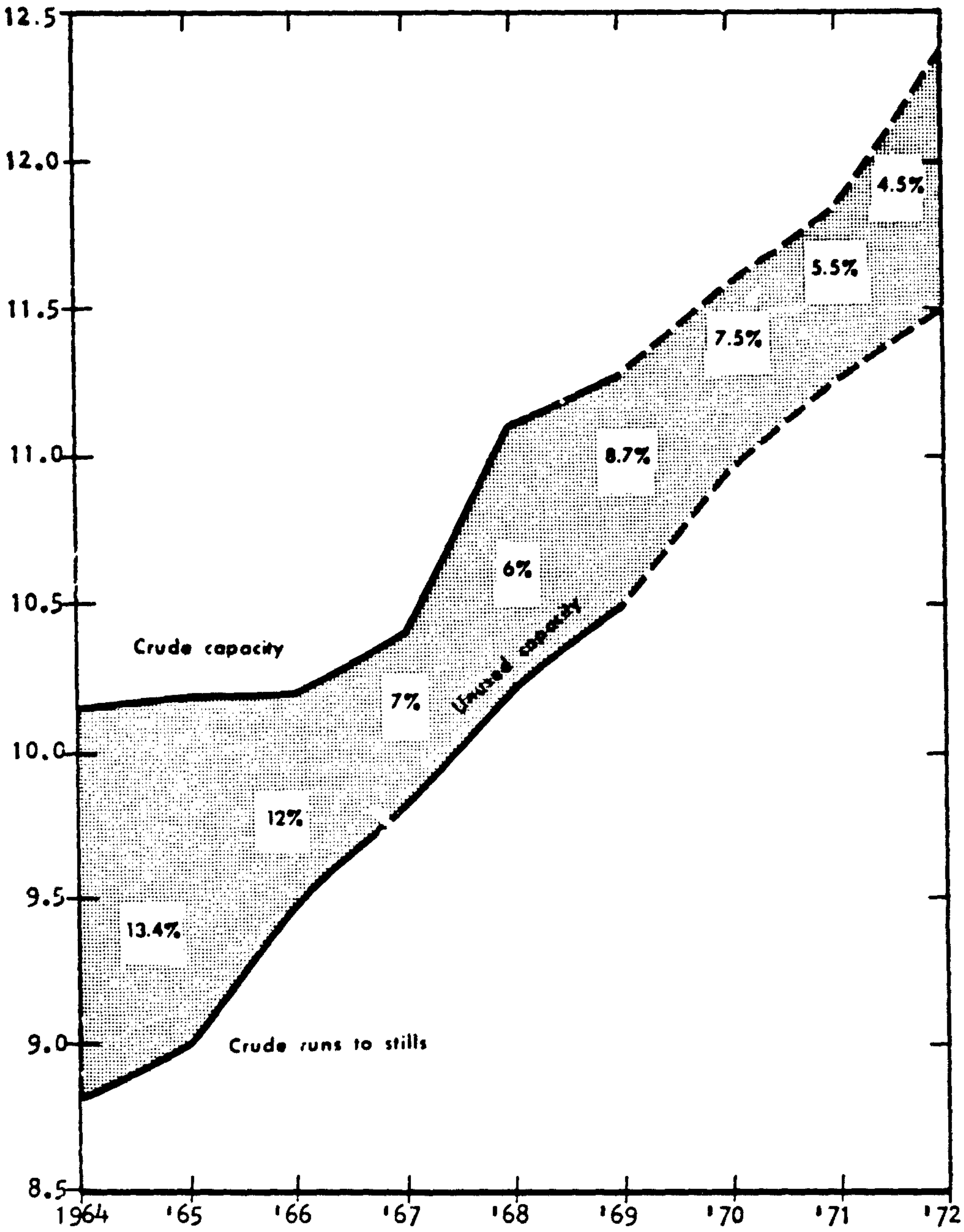


Figure 3. How Excess U.S. Refining Capacity Has Shrunk*

*Exactly what is spare capacity could be a question; conditions at each plant vary considerably. In 1971 it is estimated that unused refinery capacity exists especially on a short range emergency basis. There is 75,400 B/stream day available at shut down but still operable refineries; 50,000 barrels of this is at East St. Louis, Illinois. In 1970, there was an average capacity of 12,400,000 c/d bbls; actual daily average runs were 10,870,000 barrels or about 12% difference. (See Tables 6 and 7).

Source: Oil and Gas Journal (independent survey) Jan. 27, '69 p90

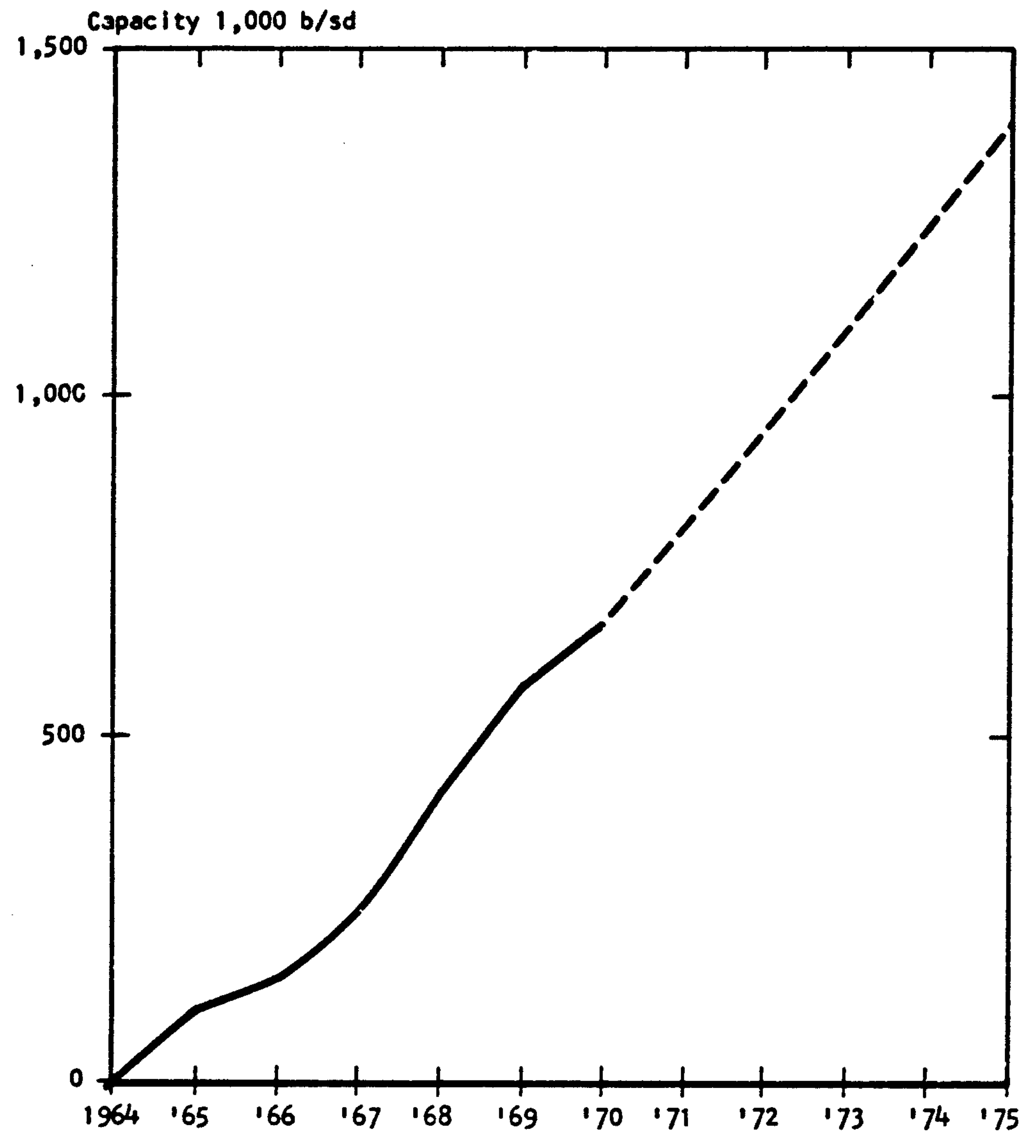


Figure 4. Outlook for Domestic Hydrocracking

1.25-million-b/sd growth the next 8 years*

Hydrocracking Growth (per O & G Journal)

1-1-70	1-1-71	1-1-72 Est.
603,375	731,505	894,505

Source: Hydrocracking- Oil and Gas Journal p2

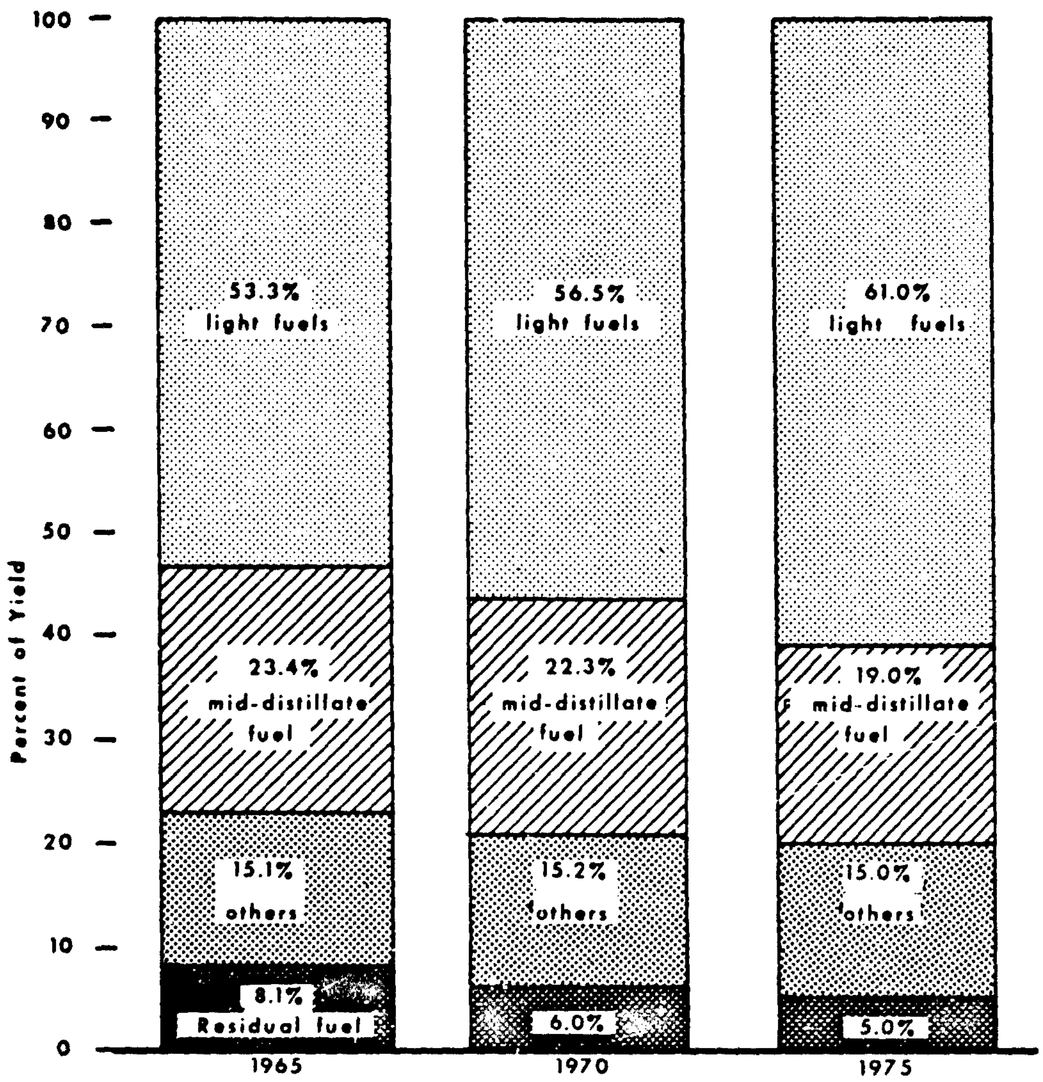


Figure 5. Changing Trends in Refinery Yields Patterns, as Percent of Crude Charged

Source: Hydrocracking- Oil and Gas Journal, p2

for capacity is expected to increase for there are no announced plans for new plants beyond 1973. It takes two years to build a small plant and more for a larger one.

In the natural gas industry, there continues to be an increased demand for gasoline and liquifiable hydrocarbons as products. The gas processing plants of the gas industry share the footlights with the refining industry as producers of solvents and raw material for the petrochemical and other industries. Extraction units capable of providing a "225 pound" product are mushrooming everywhere, even as portable units.

The new building, the conversion of units, the starting up, the modifying of old facilities, the stretching of the time on stream, the production of greater volumes of light fuels and the expanded use of hydrogen increases the problems of management and the potential dangers. (See Table 2). Since the most critical operating times are during unit start up or shut down, and there is much of this activity, the latent threat of trouble must be always in the operator's mind. It is imperative that in the haste to add capacity no potential hazards be overlooked. The complexity and sophistication of modern equipment is such that a small fire or explosion can cause much more severe damage than was true a few years back, especially if congested conditions exist in a plant. Attention given to all hazards, and building to prevent their potential damage will result in a plant having added strength which is needed to better withstand the destructive forces of war if and when one comes.

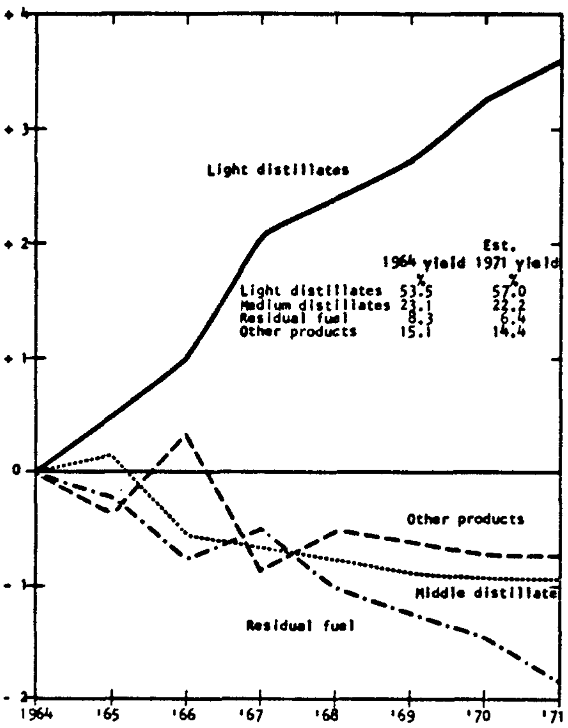


Figure 6. Trend in Yield of Average U.S. Refinery

Source: Oil and Gas Journal, Jan. 27, '69, p90

Hazard Factors

All hazards except those tabulated under "Hazards Within Plant Origin" in Table 1 might in one way or another be considered to be related to location. The geographical location of the plant and the concentration of refining and petrochemical plants in certain areas tend to increase the effects of a natural disaster or a local catastrophe. There are other factors affecting a refinery's vulnerability to disaster also related to location on local basis. These include the size and availability of space to the plant site, the nearness (or separation) of other plants—and the risk involved by having the nearby industry, the nearness to and availability of materials and supplies (a factor in the rate of recovery from damage), the availability of dependable civil services, and even the loyalty and attitude of the inhabitants in the community in which the plant is located. Potential damage to a plant during any disaster and its recovery time is, in a large plant, related to plant location. Further, most of the factors which affect a plant's susceptibility to damage need to be given consideration in planning for plant protection against sabotage and other types of enemy action.

There is no place free from all hazards whether they be of natural origin or man created. Still, much can be done in the planning of a location to make available space for growth without crowding, and to avoid, where possible, congestion of plants processing combustible and explosive materials. Such planning is important from the viewpoint of insurance protection and industrial safety as well as from that of national security. Should war come to our land, an easily damaged plant could at times become a liability. Many industrial plants have grown within available limited space far beyond the original planning. This crowding contributes greatly to the vulnerability of such operations to damage by one hazard or several hazards combined.

Many industries have much in common, especially petroleum refineries, natural gas processing plants, petrochemical operations and chemical manufacturing plants processing combustible materials. There is much similarity in some of the equipment, and any risk evaluation of these groups will find many common factors.

Studies of accidents being made by many organizations are all contributing greatly to the knowledge of the causes of industrial damage. The result of one such study conducted by the American Insurance Association[4] is reviewed here.

This publication reports a study made of 317 case histories where substantial damage to each of the companies was involved and where a reasonably clear-cut determination could be made as to the cause of the accident. In some cases, more than one factor was found; and in some cases, a primary cause involved secondary causes. There are tabulated in Table 3 as "Hazard Factors." (See Table 3).

It is evident from Table 3 that location problems and "within plant" problems stand out as major causes of chemical and allied industry plant disasters. The study further statistically shows that of the two, the "within plant" problems are responsible for almost two-thirds of the accidents. (See Table 4). The investigation reveals that explosions and/or a combination of fires and explosions accounted for almost 62% of the damage in these 317 major losses. (See Table 5).

Explosive forces, resultant damage and subsequent repair are of primary importance in this handbook. Correlated are acts of war, insurrection or sabotage which usually set off fires or explosions within a petroleum processing operation. The more one learns about the prevention and control of explosions, the more one will be prepared to cope with those created by an enemy. Explosions, whether created purposely or by accident, result in sudden releases of energy that are usually so great that the magnitude of power and the extent of resulting destruction is hard to imagine. Ordinary fire fighting procedures are nearly always inadequate.

The hazard survey cited above[4] discussed in considerable detail the circumstances favorable for an explosion and lists various types of common explosions as given in the "National Electrical Code". These are:

1. Rapid release of energy through the ignition of atmospheric mixtures of flammable gases, vapors, or combustible dusts within the explosive range.

2. Rapid release of energy through deflagration or detonation of unstable chemicals after exposure to an initiating force or energy.

4 American Insurance Association "Hazards Survey of the Chemical and Allied Industries" Technical Survey No. 3, Engineering and Safety Department, Division of Technical Services, 1968

Table 2. Fewer Refineries, More Capacity

(Capacities in 1,000 b/sd Except Where Noted)

	Companies controlling over 200,000 b/d capacity			Companies controlling less than 200,000 b/d capacity		
	1-1-70	1-1-71	1-1-72*	1-1-70	1-1-71	1-1-72*
No. companies	15	16	..	‡	‡	
No. refineries	111	105	..	151	148	..
Capacity, b/cd	9,436.4	10,141.2	10,341.2	2,718.3	2,540.2	2,731.8
Capacity, b/sd	9,885.5	10,612.9	10,822.0	2,765.9	2,672.0	2,873.6
Annual change†, %	+5.5	+7.4	+1.9	+3.9	−6.5	+7.5
% of U.S. total†	77.6	79.9	79.1	22.4	20.1	20.9
Cat cracking	4,774.2	5,010.5	5,040.8	1,089.6	957.9	975.4
% of crude	48.2	47.2	46.6	39.3	35.8	33.9
Cat reforming	2,178.2	2,378.7	2,639.4	598.0	523.6	569.9
% of crude	22.0	22.4	24.3	21.6	19.6	19.8
Hydrocracking	548.1	637.4	794.9	55.3	94.1	99.6
% of crude	5.5	6.0	7.3	2.0	3.5	3.4
Other hydroprocessing	3,449.3	3,814.8	4,074.5	603.2	529.7	588.3
% of crude	34.8	35.9	37.6	21.8	19.8	20.4
Alkylation	605.8	602.7	630.2	142.9	172.7	178.2
% of crude	6.1	5.6	5.8	5.2	6.5	6.2

*Estimated. †In b/cd. ‡approximately 115

Courtesy Oil and Gas Journal, March 22, 1971, p86

3. Rapid release of energy through decomposition or exothermic chemical reactions.

4. Rapid release of energy through the mechanical failure of a pressure container as a result of mechanical defect or the generation of excessive pressures."

Just how much damage will occur depends on the nature of the process, the age of the equipment, the nearness to other units or congestion, and the built-in strength of the equipment located in the vicinity of the explosion.

Major losses have occurred in many plants, and there is a specific cause or a combination of causes for such happenings. Constant planning for the prevention of these accidents is vital, but *building in extra strength to minimize danger to facilities and taking other preventive measures* is also urgent. This is especially necessary in petroleum refineries where there is a trend toward greater use of hydrogen, oxygen, chlorine, nitrogen, and other elements. As operating temperatures and pressures become higher, many modern processes operate near explosive ranges.

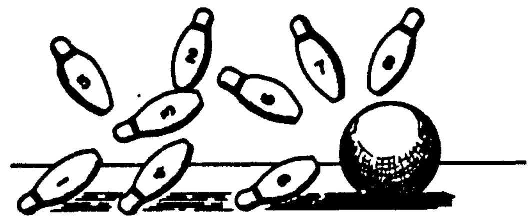
Considering the complexity of many of the modern processes and the fact that there is still something to be learned about them, any generosity given to the safety factor in the design of equipment would certainly be good insurance.

Design limitations commonly used by structural engineers are often dictated by the existing minimums of codes and by a tight budgets. The building of bomb blast-resistant structures, a war time consideration, is not often given much thought. There is certainly ample justification, based on the frequency and the magnitude of recent industrial losses, to apply many of the principles and much of the research done by the Office of Civil Defense, and many other groups, to the design of facilities in spite of the fact that such studies are often oriented toward protection of industry from nuclear blasts. Application of these basic principles would involve searching out those relatively weak areas of an installation and correcting them, or when designing new plants, to write into the specifications those features that will correct situations found to have been trouble spots in the past. Much information is available on the design of bomb-resistant hardened structures through the Office of Civil Defense. There are places where a bomb-resistant control center would have paid off.

The protection of employees from the possible hazards of of war also has direct application to modern liquid fuel production plant planning and specification preparation. Much has been done to make refineries safe places to work. In 1969, the refining industry had only five disabling injuries per million man-hours of work, an outstanding record. Yet, few refineries could operate in nuclear war conditions for none are prepared to cope with radioactive fallout. Any war effort depends on liquid fuels. To be prepared for possible nuclear warfare, some provisions are necessary to permit an undamaged installation to operate in a highly charged atmosphere.

Table 3

HAZARD FACTORS



A systematic survey has been undertaken on several hundred large loss fires and explosions which occurred in the chemical and allied industries over the past twenty years. The case histories utilized in this study included only those where enough information was available to assign hazard factors which contributed to the losses. The following "hazard factors" have been utilized:

1. *Plant site problems*—unusual exposure to natural calamities such as windstorms, floods and earthquakes—poor location with respect to adequate water supply and other utilities—exposure to severe hazards of nearby plants—unreliability of public fire and emergency protection—traffic difficulties for emergency equipment—inadequate waste disposal facilities—climatic problems requiring indoor facilities for hazardous processes.

2. *Inadequate plant layout and spacing*—congested process and storage areas—lack of isolation for extra-hazardous operations—exposure of high values and difficult-to-replace equipment—lack of proper emergency exit facilities—insufficient space for maintenance or emergency operations—sources of ignition too close to hazards—critical plant areas exposed to hazards—inadequate hazard classification of plant areas.

3. *Structure not in conformity with use requirements*—disregarding code requirements with regard to the buildings, electrical facilities, drainage, etc.—lack of fire-resistive structural supports where required—failure to provide blast walls or cubicles to isolate extra hazardous operations—inadequate explosion venting and ventilation of buildings—insufficient exit facilities—electrical equipment not in conformance to codes—unprotected critical wiring.

4. *Inadequate material evaluation*—insufficient evaluation of the fire, health and stability characteristics of all materials involved—lack of established controls for the quantities of material involved—inadequate assessment of effect of processing environment on hazard characteristics of materials—lack of information on dust explosion tendencies of materials—toxicological hazards of materials not properly evaluated—incomplete hazard material inventory for the plant—improper packaging and labeling of chemicals.

5. *Chemical process problems*—lack of required information on process temperature or pressure variations—hazardous by-products or side reactions—inadequate evaluation of the process reactions—lack of identification of processes subject to explosive reactions—inadequate evaluation of environment—requirement for extreme process conditions overlooked.

6. *Material movement problems*—hazards due to lack of control of chemicals during unit operations—inadequate controls for hazardous dusts—piping problems—improper identification of hazardous materials during transportation—loading and unloading problems in the plant—flammable gas and vapor problems—inadequate control of heat transfer operations—explosion problems in pneumatic conveyors—waste disposal and air polution problems.

7. *Operational failures*—lack of detailed descriptions and recommended procedures for operating all sections of the plant—poor training program—lack of supervision—inadequate start-up and shut-down procedures—hazards due to poor inspection and housekeeping programs—inadequate control of hazards through permit systems—lack of emergency control plans—inadequate drills.

8. *Equipment failures*—hazards built into the design of equipment—corrosion or erosion failures—metal fatigue—defective fabrication—inadequate controls—process exceeded design limitation—poor maintenance program—inadequate repair and replacement program—lack of "fail-safe" instrumentation—poor check on contruction criteria or material specifications.

9. *Ineffective loss prevention program*—inadequate support of top management—lack of assigned responsibility—poor accident prevention program—insufficient fire protection manpower; equipment and organization—ineffective explosion prevention and control program—lack of emergency planning—poor check on boiler and machinery risks—lack of loss prevention coordination with other plant groups—ineffective investigation of accidents.

Source: American Insurance Association- "Hazard Survey of Chemical and Allied Industries" - Technical Survey #3, p13

Table 4

Hazard Factor	Number of Times Assigned	Percentage of Total
(1) Plant Site Problems	16	3.5%
(2) Inadequate Plant Layout and Spacing	9	2.0%
(3) Structures Not in Conformity with Use Requirements	14	3.0%
(4) Inadequate Material Evaluation	93	20.2%
(5) Chemical Process Problems	49	10.6%
(6) Material Movement Problems	20	4.4%
(7) Operational Failures	79	17.2%
(8) Equipment Failures	143	31.1%
(9) Ineffective Loss Prevention Program	37	8.0%
	Totals 460	100.0%

Table 5

Study of the 317 case histories placing them in categories of (1) fires, (2) explosions, or (3) both fires and explosions, reveal the following:

	Number of Times Assigned	Percentage of Total
(1) Fires (only)	122	38.5%
(2) Explosions (only)	111	35.0%
(3) Fires and Explosions	74	26.5%

Chapter III

RISK SUSCEPTABILITY DUE TO LOCATION - NATURAL HAZARDS

The location of a refinery is chosen by its builders with considerable care. Many factors are evaluated before new construction is started. A complete list of these considerations would be long because those items important to one company might not be so important to another. In this writing, we are concerned with plant location because of the natural hazards likely to be encountered at various plant sites, the lack of decentralization or congestion of industry, and the problems created by such in case of war.

Hazard studies discussed above[4] point out that many plant losses are related in one way or another to the location of the plant in question. The concentration of refineries in the Gulf Coast area, an area frequented by hurricanes and wind velocities of 200 miles per hour, plus the accompanying flooding of low areas, greatly concerns Civil Defense planners. The building of refineries in hilly areas subjected to earthquakes is another impending danger. The concentration of petrochemical plants around refineries only magnifies the vulnerability of these industries in time of war and only increases the potential of loss to severe weather. The clustering of large refineries in a relatively few locations makes massive losses possible to our fuel processing capacity with only a few nuclear weapons. The petroleum refining, natural gas, and petrochemical industries are of such vital importance to our economy as a nation and so vital to any war effort that a major loss of these facilities is alarmingly detrimental to the welfare of the citizens of our nation.

Location of Refineries

Table 6 shows those states with refining capacity and the number of plants supplying our refining capacity. Of the fifty states of our country, only eighteen refine 2,000 barrels or more of crude oil per day; eleven states have no reported capacity. Table 7 shows the companies with operating capacity in excess of 200,000 barrels. These sixteen companies process in excess of ten million barrels of oil per day in the United States.

Figure 7 is a map showing the approximate location of the bulk of the refining capacity of the country. The concentration of major refining capacity in ten or twelve areas permits serious potential losses from nuclear attack.

Table 8 is a list of refineries reporting able to process 50,000 barrels or more of crude per day and their locations. The total refining capacity in the United States in 1971 was 12,681,000 barrels per day.

Natural Hazards

Many of the plants of California, Delaware, Louisiana, Mississippi, New Jersey and Pennsylvania are located on tide water.

These plants are subjected to the severe weather related to the oceans or Gulf of Mexico. High wind velocities and high water are frequent visitors in some of these areas. The California plants have the potential threat of earthquakes, landslides, subsidence and flooding. (A seismic wave generated by an earthquake in the Aleutians caused 173 deaths and over $25,000,000 damage in Hawaii alone.) Flooding created by seismic shock waves often causes more damage than the earthquake.

Many of the refineries in the interior of the country are in areas visited occasionally by tornadoes which strike with devastating forces. The high wind velocities and negative pressures have damage capabilities that are comparable to those of a nuclear blast providing the point of detonation of a bomb is a few miles distant from the plant. Severe winter weather affects the plants in the northern part of the country, although damaging ice storms also visit the south nearly every year. There is not direct similarity between snows, ice storms and freezing and the damage caused by possible enemy action except these can seriously damage or completely disrupt overhead electric service. It would appear that the obsolescence of overhead wires would discourage repair, but each year areas are without power and repair crews continue their icy job of rebuilding overhead lines. From 1936 through 1966, over 3000 deaths were attributed to winter storms, with 1960 being a year of note when 354 died as a result of such storms. Deposits of ice over eight inches in diameter, or a loading of nine to twelve pounds per foot were built up on the wires in Northern Idaho, Michigan, Pennsylvania and New York. Even Mississippi and Louisiana have serious storms of record.

Winter storms are discussed in detail in ESSA pamphlets which are available from the Superintendent of Documents, Washington, D. C.

Overhead wires of all types are vulnerable to enemy attack and make power disruption the number one target of saboteurs.

The Environmental Science Services Administration of the Federal Government proposed a Natural Disaster Warning System in October 1965.[6] It was recognized that no state is entirely free of some adverse natural occurrence. Advanced warnings given to people that a flood, hurricane, tornado, or other adverse weather was coming has allowed them to seek safety and shelter, and in many cases the warning has made life and property protection possible.

The President has declared an average of fifteen disaster areas a year since the enactment of the Federal Dis-

6 U. S. Department of Commerce "A Proposed Nationwide Natural Disaster Warning System-(NADWARN)" Environmental Science Services Administration,* October 1965

*See Acknowledgements for new name.

Table 6. Survey of Operating Refineries in the U.S. (State Capacities as of Jan. 1, 1971)*[5]

State	No plants	Crude capacity b/cd	Crude capacity b/sd	Vacuum distillation	Charge capacity - b/sd: Thermal operations	Cat cracking: Fresh feed	Cat cracking: Recycle	Cat reforming	Cat hydro-cracking	Cat hydro-refining	Cat hydro-treating	Production capacity - b/sd: Alkylation	Aromatics-isomerization	Lubes	Asphalt	Coke (t/d)
Alabama	5	37,670	39,850	22,890	–	–	–	1,500	–	–	6,500	–	–	–	13,400	–
Alaska	2	37,500	39,000	–	–	–	–	–	–	–	–	–	–	–	333	–
Arkansas	6	93,500	95,000	44,000	16,000	36,500	10,200	16,500	–	5,000	21,000	6,500	–	5,250	9,500	420
California	34	1,700,925	1,787,000	830,650	483,344	492,600	139,500	432,050	286,300	73,500	620,700	90,100	13,780	28,100	89,500	13,080
Colorado	4	44,660	48,750	10,000	17,250	15,500	8,500	11,700	–	–	16,900	–	–	–	4,800	460
Delaware	1	140,000	150,000	90,700	42,000	62,000	44,000	45,000	–	–	88,000	5,000	–	–	–	1,500
Florida	1	3,100	3,250	2,400	–	–	–	–	–	–	–	–	–	–	1,500	–
Georgia	2	8,805	10,300	–	–	–	–	–	–	–	–	–	–	–	8,800	–
Hawaii	1	36,000	36,840	–	–	14,445	14,445	–	1,566	–	–	4,220	1,560	–	615	–
Illinois	10	846,100	882,900	311,900	128,800	317,700	117,100	240,000	64,500	32,000	302,600	73,100	10,100	5,700	37,400	2,280
Indiana	9	598,300	618,300	222,700	65,800	226,300	62,900	88,900	–	39,500	141,360	32,800	7,700	12,400	32,560	1,730
Kansas	11	377,950	393,800	98,450	40,200	147,060	65,060	77,200	2,960	3,000	81,100	36,070	1,400	4,000	21,250	1,286
Kentucky	3	150,430	156,500	59,000	10,500	61,000	24,400	26,000	–	–	39,000	–	16,800	–	12,500	–
Louisiana	17	1,306,526	1,356,400	418,600	129,800	491,100	125,300	306,100	83,100	25,000	188,700	96,800	14,000	25,500	18,900	4,540
Maryland	2	18,400	19,400	8,000	–	–	–	–	–	–	–	–	–	–	11,900	–
Michigan	7	156,800	165,000	42,000	10,500	56,000	30,150	31,360	–	16,300	37,960	7,850	2,000	–	11,660	330
Minnesota	3	151,500	157,700	44,600	23,000	57,700	21,300	27,900	–	–	66,900	9,500	–	–	14,000	1,300
Mississippi	5	311,700	333,900	141,550	6,700	57,500	31,000	43,700	27,000	3,000	18,000	13,000	12,000	–	40,320	320
Missouri	1	83,000	84,700	35,000	11,000	38,000	18,000	41,000	–	–	20,000	4,500	–	–	20,000	400
Montana	9	126,800	136,350	45,150	13,900	41,800	36,900	24,700	12,800	–	60,650	8,400	3,780	–	17,875	260
Nebraska	1	5,000	5,500	2,000	–	2,000	2,000	1,000	–	–	–	–	–	–	–	–
Nevada	1	500	–	500	–	–	–	–	–	–	–	–	–	–	–	–
New Jersey	6	519,800	561,100	268,800	36,700	257,500	91,800	77,000	–	14,800	173,800	21,800	–	8,520	54,200	1,010
New Mexico	5	42,690	44,425	9,800	1,500	11,200	7,200	10,000	–	–	10,650	3,050	–	–	750	–
New York	2	87,400	92,000	36,000	4,500	38,000	14,000	19,500	–	16,000	24,100	2,800	7,000	–	10,500	–
North Dakota	2	55,000	57,000	–	1,200	21,000	10,300	9,000	–	–	9,000	2,800	–	–	–	–
Ohio	8	532,000	574,500	180,800	28,600	183,500	78,000	146,700	79,000	26,000	148,300	33,100	–	2,300	31,400	1,162
Oklahoma	13	463,701	480,000	137,750	75,700	181,050	56,770	86,530	4,200	–	82,450	37,080	5,560	11,850	15,950	1,428
Oregon	1	11,000	12,000	12,000	–	–	–	–	–	–	–	–	–	–	6,400	–
Pennsylvania	12	649,070	679,440	277,728	62,250	261,100	55,300	176,400	32,000	66,000	232,360	29,400	12,260	32,886	22,000	–
Rhode Island	1	7,500	10,000	5,000	–	–	–	–	–	–	–	–	–	–	6,800	–
Tennessee	1	28,500	30,000	16,000	–	12,000	3,500	–	–	–	–	3,000	–	–	3,000	–
Texas	43	3,468,750	3,622,800	1,189,200	321,100	1,221,900	307,000	865,800	138,100	176,400	1,246,920	218,608	192,580	86,400	56,250	6,247
Utah	5	117,700	122,300	34,150	–	46,500	17,350	18,600	1,000	–	14,000	10,875	2,000	–	2,850	–
Virginia	1	51,400	52,900	–	15,000	29,000	15,000	8,000	–	16,000	8,100	–	–	–	–	900
Washington	6	222,500	234,500	70,600	7,000	81,800	29,600	30,700	–	8,600	91,700	18,300	2,900	–	4,700	–
West Virginia	2	8,370	9,100	4,000	–	–	–	2,960	–	–	3,950	–	–	2,200	–	–
Wisconsin	2	39,000	40,100	18,000	–	9,500	1,000	4,200	–	–	9,200	1,200	–	–	–	–
Wyoming	9	138,850	161,580	63,000	5,800	52,800	18,300	27,110	–	16,800	48,380	4,500	–	1,070	18,100	140
Total**	253	12,681,387	13,284,986	4,740,918	1,557,944	4,512,545	1,455,866	2,885,290	731,505	536,400	3,808,060	775,386	306,840	221,786	588,703	38,772

5 Oil and Gas Journal, March 24, 1971. Capacities reported January 1, 1971.
* 1970 saw a reduction in the number of refineries operating by 10, but an increase in total refining capacity occurred.

Table 7. Refiners Controlling Over 200,000 b/cd Capacity*

	No. refin-eries	Crude capacity b/cd	Crude capacity b/sd	Cat cracking Feed b/sd	Cat cracking Recycle b/sd	Cat reforming b/sd	Hydro-cracking b/sd	Other hydro-processing b/sd	Alkyl-ation b/sd
1. Humble	6	1,079,000	1,130,000	503,500	100,400	208,400	69,900	460,500	86,700
2. Shell	8	1,068,500	1,097,000	362,300	126,200	277,400	79,900	650,000	74,860
3. American	11	1,040,000	1,078,500	425,000	174,250	218,000	40,000	282,300	66,000
4. Texaco	12	1,029,500	NR	426,600	170,620	232,800	38,900	330,400	63,400
5. Standard (Calif.)	11	967,400	1,026,440	212,245	83,845	177,100	147,455	178,100	40,620
6. Mobil	9	792,800	833,800	279,000	51,300	202,300	45,500	326,600	46,000
7. ARCO	5	702,000	731,700	222,200	23,100	167,200	51,500	334,100	30,700
8. Gulf	7	686,800	704,800	253,500	47,000	179,400	37,500	333,000	42,300
9. Sun	5	458,000	484,000	211,000	75,400	136,300	24,000	129,000	37,200
10. Union	5	444,000	463,900	148,900	52,000	78,000	21,000	182,700	30,200
11. Sohio/BP	4	438,600	466,000	142,600	40,500	123,500	55,000	171,300	14,000
12. Phillips	6	398,000	NR	186,900	63,380	120,700	24,000	106,700	46,300
13. Conoco	7	299,100	315,200	95,200	39,200	84,250		96,350	12,850
14. Cities Service	2	281,000	288,000	139,600	58,900	49,000	2,700	42,450	5,000
15. Ashland	5	259,500	271,000	101,000	40,400	41,500		76,000	6,000
16. Getty	2	207,000	220,000	92,000	62,000	65,000		115,300	11,000
Total	105	10,141,200	10,612,940	3,801,545	1,208,995	2,361,650	637,355	3,814,800	602,720

*Note that 16 companies with 105 refineries handle 79.9% of the country's capacity. Fewer refineries are processing more oil than in the past. In the first half of 1971, 253 plants had a capacity of 12,681,000 barrels.

The Oil and Gas Journal—March 22, :971

aster program.[7] As many as twenty-six natural disaster areas have been declared within a single year. Economic losses of our country each year average between eleven and fifteen billion dollars and take from five hundred to six hundred lives, to say nothing of the impact on the lives of the thousands of injured and other survivors.

The incidence of natural disasters, their severity, and the history of the extent of the resultant damage could influence the decision as to where to locate a refinery. Figure 8 shows the national distribution of these disasters. The areas subjected to high wind velocities of a hurricane and of a tornado stand out quite dramatically. The frequency of earthquakes usually is significant to the west coastal area including Alaska, but moderate to major earthquakes have occurred in northeastern, southeastern, central and south central United States as well.

Hurricanes- The location of many large refineries in the Gulf of Mexico and the Atlantic Coast areas makes a review of hurricane history especially pertinent. Much of the damage caused by a hurricane is due to high tides, flooding and torrential rains; but extremely high wind velocities and the projectiles and debris carried with the wind give cause for great concern to the management of any refining installation in areas of known hurricane path, for few if any refineries are designed to withstand the full blast of the tropical demons.

A hurricane is a large mass of storm clouds whirling counterclockwise in the northern hemisphere like a giant dust devil of the plains, but of course much larger. They are generally of tropical marine origin and can generate winds in excess of 200 miles per hour, a wind loading of over 144 pounds per square foot.

The paths frequented by the North Atlantic hurricanes from 1955 to 1964 are shown in Figure 9. Since 1900, at least 39 major hurricanes have been of record. Some were quite devastating. The importance of hurricane study was brought to public attention in September 1900 when a hurricane struck Galveston, Texas. Over 6000 lives were lost when a storm tide inundated Galveston Island. Wind gusts of at least 120 miles per hour were reported, but wind measuring devices blew down, so the record is not accurate. Serious flooding nearly always accompanies a hurricane. In September 1928, southern Florida was struck by only 75 mile an hour winds, but these were strong enough to blow the water from Lake Okeechobee into a populated area causing the death of 1836 persons. Each year some area and industry suffer from hurricane damage.

The damage done by hurricane Carla (like Audrey in 1957) is still a subject of conversation in those affected areas of the Gulf Coast. From September 3rd to 15th, 1961, one of the largest hurricanes of history, with winds up to an estimated 175 miles per hour, caused the death of 46 people and raised havoc with the industries concentrated in the area. Figures 10 and 11 show some of the damage, some quite comparable to that of a nuclear attack. More damage to refinery equipment was reported done by Carla than by the Texas City explosion. The people of the Gulf Coast were still mindful of the damage done by Audrey in 1957 when 390 people were killed, many in their sleep, and when water from the Gulf invaded inland for at least twenty-five

[7] Federal Disaster Act- Public Law 81-875

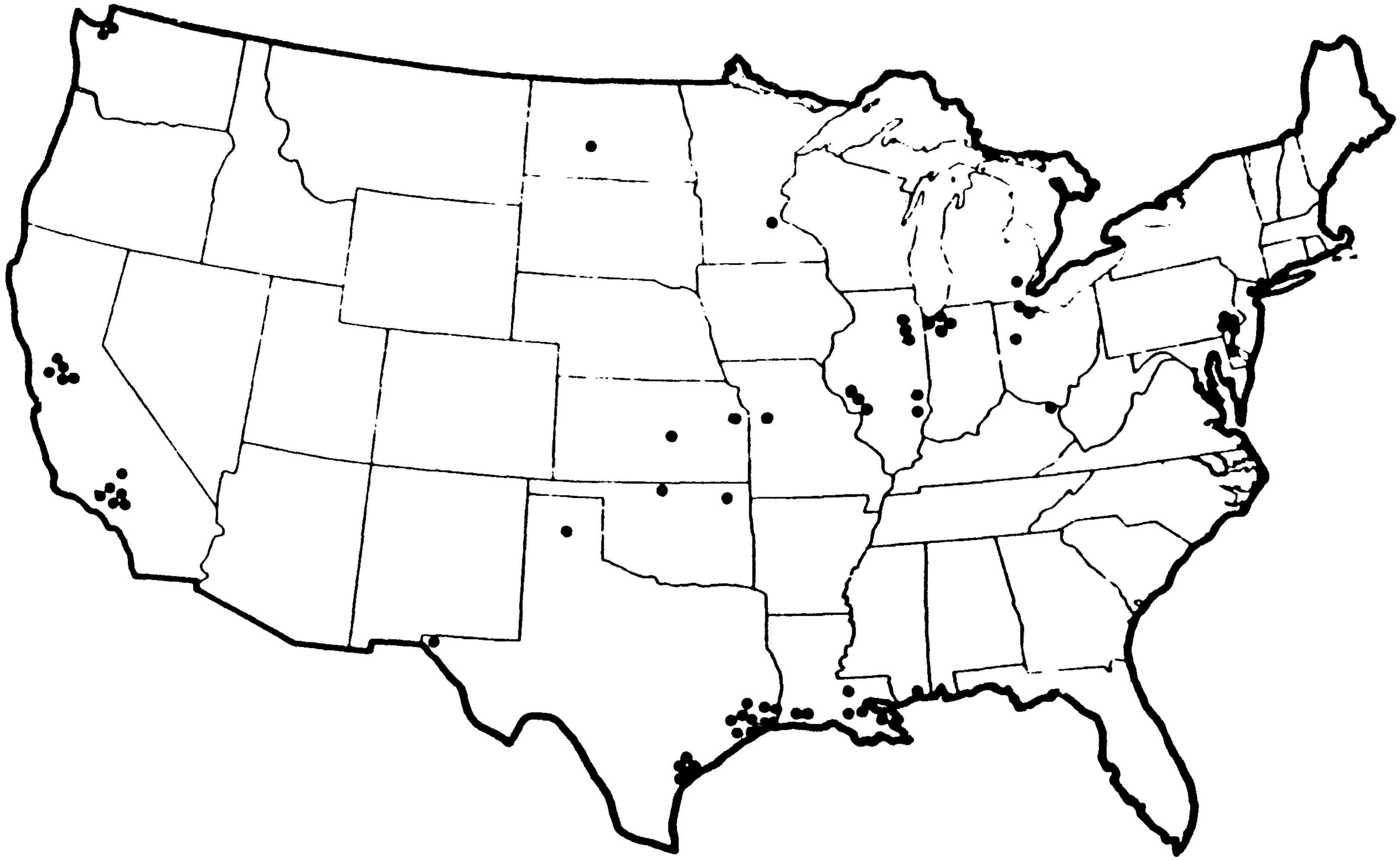


Figure 7. The Location of Refineries Processing 50,000Barrels of Crude Oil Per Day or More

Table 8. Refineries of 50,000 Barrels of Capacity per Stream Day (January 1, 1971)

	Capacity B/cd	Capacity B/sd
California		
Atlantic-Richfield Co. Richfield Div. Carson	165,000	173,000
Gulf Oil Corp. - Santa Fe Springs	49,800	52,000
Humble Oil and Ref. Co. - Benecia	80,000	90,000
Mobile Oil Co. - Torrance	123,500	130,000
Phillips Pet. Co. - Avon (Martinez)	110,000	NR
Shell Oil Co. - Martinez	100,000	103,000
Shell Oil Co. - Wilmington (Dominguez)	86,000	88,000
Standard Oil of Calif.		
Western Operations Inc. - El Segundo	220,000	NR
Western Operations Inc. - Richmond	190,000	NR
Texaco, Inc. - Wilmington	77,000	NR
Union Oil Co. of Calif. - Rodeo (Oleum Ref.)	60,000	62,000
Union Oil Co. of Calif. - Wilmington	104,000	107,000
State Total (with others)	1,700,925	1,787,000
Delaware		
Getty Oil Co.	140,000	150,000
State Total	140,000	150,000
Illinois		
American Oil Co. - Wood River	94,500	97,300
Clark Oil & Ref. Co. - Blue Island	65,000	68,000
Marathon Oil Co. - Robinson	96,400	102,500
Shell Oil Co. - Wood River	245,000	252,000
Texaco, Inc. - Lawrenceville	92,000	NR
Texaco, Inc. - Lockport	76,000	NR
Union Oil Co. of Calif. - Lemont	140,000	NR
State Total (with others)	846,100	882,900
Indiana		
American Oil Co. - Whiting	303,000	309,000
Atlantic-Richfield Co. - East Chicago	135,000	140,000
Cities Service Oil Co. - East Chicago	56,000	58,000
Mobile Oil Corp. - East Chicago	47,000	50,800
State Total (with others)	598,300	618,300
Kansas		
Phillips Petroleum Co. - Kansas City	85,000	NR
Skelly Oil Co. - El Dorado	67,000	70,000
State Total (with others)	377,950	393,800
Kentucky		
Ashland Oil and Ref. Co. - Cattlettsburg	125,000	130,000
State Total (with others)	150,430	156,500

NR = No report

Table 8. Refineries of 50,000 Barrels of Capacity per Stream Day (January 1, 1971) (Continued)

	Capacity B/cd	Capacity B/sd
Louisiana		
Cities Service Oil Co. - Lake Charles	225,000	230,000
Continental Oil Co. - Westlake (Lake Charles)	71,000	74,000
Humble Oil & Ref. Co. - Baton Rouge	434,000	449,000
Shell Oil Co. - Norco	240,000	250,000
Tenneco Oil Co. - Chalmette	84,000	87,000
Texaco, Inc. - Convent	145,000	NR
State Total (with others)	1,306,526	1,356,400
Michigan		
Marathon Oil Co. - Detroit	48,000	50,000
State Total (with others)	156,800	165,000
Minnesota		
Great Northern Oil Co. - Pine Bend (St. Paul)	87,000	90,000
State Totals (with others)	151,500	157,700
Mississippi		
Standard Oil Co. - (Kentucky) Sub. So Cal - Pascagoula	270,000	290,000
State Total (with others)	311,700	333,900
Missouri		
American Oil Co. - Sugar Creek	83,000	84,700
State Total	83,000	84,700
New Jersey		
Chevron Oil Co. - Eastern Div. Perth Amboy	80,000	85,500
Hess Oil & Chemical Corp. - Port Reading (Sewaren)	70,000	75,000
Humble Oil & Ref. Co. - (Linden)	155,000	163,000
Mobile Oil Corp. - Paulsboro	90,800	93,600
Texaco, Inc. - Westville	91,000	NR
State Total (with others)	519,800	551,100
New York		
Ashland Oil Inc. - N. Tonawanda	47,500	50,000
State Total (with others)	87,400	92,000
North Dakota		
American Oil Co. - Mandan	50,000	52,000
State Total (with others)	555,000	57,000

NR = No Report

Table 8. Refineries of 50,000 Barrels of Capacity per Stream Day (January 1, 1971) (Continued)

	Capacity B/cd	Capacity B/sd
Ohio		
Ashland Oil Inc. - Canton	57,000	60,000
Standard Oil Co. (Ohio) - Lima	136,400	144,000
Standard Oil Co. - Toledo	117,600	128,000
Sun Oil Co. - Toledo	112,000	120,000
State Total (with others)	532,000	574,500
Oklahoma		
Continental Oil Co. - Ponca City	112,000	117,000
Sun Oil Co. - Duncan	49,000	50,000
Sun Oil Co. - Tulsa	89,000	90,000
Texaco - West Tulsa	51,000	NR
State Total (with others)	463,701	480,800
Pennsylvania		
Atlantic Richfield - (Atl. Div.) Philadelphia	160,000	165,000
BP Oil Corp. - Marcus Hook	105,000	110,000
Gulf Oil Corp. - Philadelphia	168,100	172,000
Sun Oil Co. - Marcus	158,000	172,000
State Total (with others)	649,070	679,440
Texas		
American Oil Co. - Texas City	325,000	338,000
Atlantic-Richfield Co. - Houston	210,000	220,000
BP Oil Corp. - Port Arthur	80,000	84,000
Champlin Petroleum Co. - Corpus Christi	57,000	58,200
Charter Oil Co. - Houston	72,000	73,000
Chevron Oil Co. - (West. Div.) El Paso	65,000	70,000
Coastal States Petrochemical Co. - Corpus Christi	133,000	140,000
Cosden Oil & Chemical Co. - Big Spring	58,000	60,000
Gulf Oil Co. - Port Arthur	331,200	338,500
Hess Oil & Chem. Co. - Corpus Christi*	47,000	50,000
Humble Oil and Ref. Co. - Baytown	345,000	360,000
Mobile Oil Corp. - Beaumont	335,000	350,000
Phillips Petroleum Co. - Borger	90,000	NR
Phillips Petroleum Co. - Sweeny	85,000	NR
Shell Oil Co. - Deer Park (Houston)	255,000	268,000
Southwestern Oil & Ref. Co. - Corpus Christi	NR	52,000
Suntide Refining Co. - Corpus Christi	50,000	52,000
Texaco, Inc. - Port Arthur	320,000	NR
Texaco, Inc. - Port Neches	53,000	NR
Texas City Refining, Inc. - Texas City	60,000	63,000
Union Oil Co. of Calif. - Nederland Beaumont	105,000	NR
State Total (with others)	3,469,750	3,622,800

NR = No Report

*This plant seriously damaged by Hurricane Celia and will not be reopened.

Table 8. Refineries of 50,000 Barrels of Capacity per Stream Day (January 1, 1971) (Continued)

	Capacity B/cd	Capacity B/sd
Virginia		
American Oil Co. - Yorktown	51,400	52,900
State Total	51,400	52,900
Washington		
Mobil Oil Corp. - Ferndale	55,000	58,400
Shell Oil Co. - Anacortes	88,000	90,000
Texaco, Inc. - Anacortes	65,000	NR
State Total (with others)	225,500	234,500
U.S.A. Total	12,681,387	13,284,985

New Plants under construction are

		Due
Atlantic Richfield (Bellingham, Washington)	100,000	1971
Gulf Oil Corp. - (Belle Chase, Louisiana)	160,000	1972
Mobile Oil Corp. - (Joliet, Illinois)	Large	1972 or 1973

miles. The announcement of Carla's approach found them highly alert as to the possible consequences of such a storm. Even large boats were tossed inland taking buildings and equipment with them.

Carla was the largest hurricane yet to hit the area; the "eye" was over thirty miles across, and winds of hurricane force extended three hundred miles from its center. Carla's 600 mile diameter spinning mass, in its western trend, almost jabbed its way into several important coastal oil and refining areas of Louisiana only to be turned back by a strong high pressure area fortunately lying inland. New Orleans, Lake Charles, Baytown and Houston- all at times appeared to be in its path. Texas City -Brazosport, Texas, industrial complex was at one time threatened. Here again, by a quirk of atmospheric gymnastics and with the help of a forty-eight hour Canadian inland high, the area was for the most part spared, and the storm moved on past Galveston and on towards Corpus Christie. All coastal towns experienced some of the storm's fury. The full story is told in the reference cited.[8] Much damage and many lives were saved because of the early warnings and alertness of the many government and volunteer agencies that worked in close teamwork. Figure 12 shows people who were sheltered in the Galveston Court House. Civil buildings are usually poor places to go to in a disaster since they are not equipped with cooking, sleeping, and adequate toilet facilities. Hurricane preparedness sponsored by the Office of Emergency Preparedness, the Office of Civil Defense, and the Department of the Interior clearly demonstrated the value of such planning.

Over a seventy-seven year period, we have experienced an average of four hurricanes a year. Some, like Betsy in 1965 caused upward to five billion dollars damage. Each one has created high water in the areas within its path; some have created tides twenty feet above normal. The average was six hurricanes a year during the past ten years. There are those who think changing weather conditions are putting the eastern industrialized third of the United States into "hurricane alley". Not all agree.

Since 1886, 642 tropical storms and hurricanes add 378 hurricanes have been reported[9] affecting the United States.

Table 10[6,10] shows the loss of life and the estimated property damage done by hurricanes from 1915 to 1964.

In the United States, winds of 125 to 150 miles per hour are not uncommon in hurricanes,[10] and winds in excess of 200 miles per hour have occurred in several storms based on structural damage done by them. Any important structures built in a path frequented by hurricanes need to be able to withstand winds of at least 125 miles per hour, and unless the management wishes to gamble with nature, 150 to 200 miles per hour. Whirling fingers of wind within the hurricane can rake through an area like a tigers clawed paw.

8 Department of Defense Office of Civil Defense- "Hurricane Carla" December 22, 1961

9 U. S. Department of Commerce "Notes on Hurricanes" April 1966, LS6002 Rev.

10 U. S. Department of Commerce "Some Devastating North Atlantic Hurricanes of the 20th Century" Environmental Science Services Administration, April 1966. CS 6506 Rev.

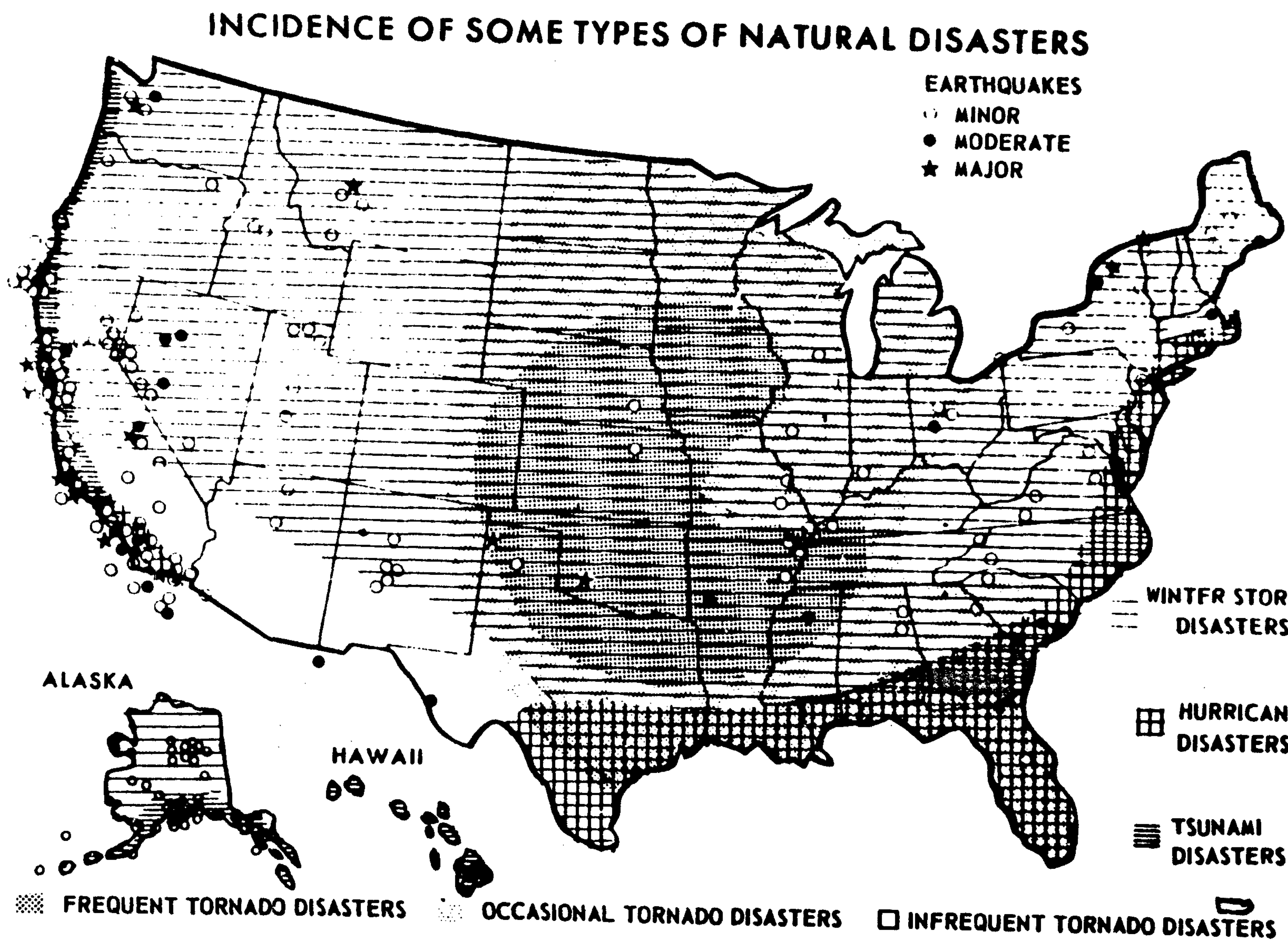
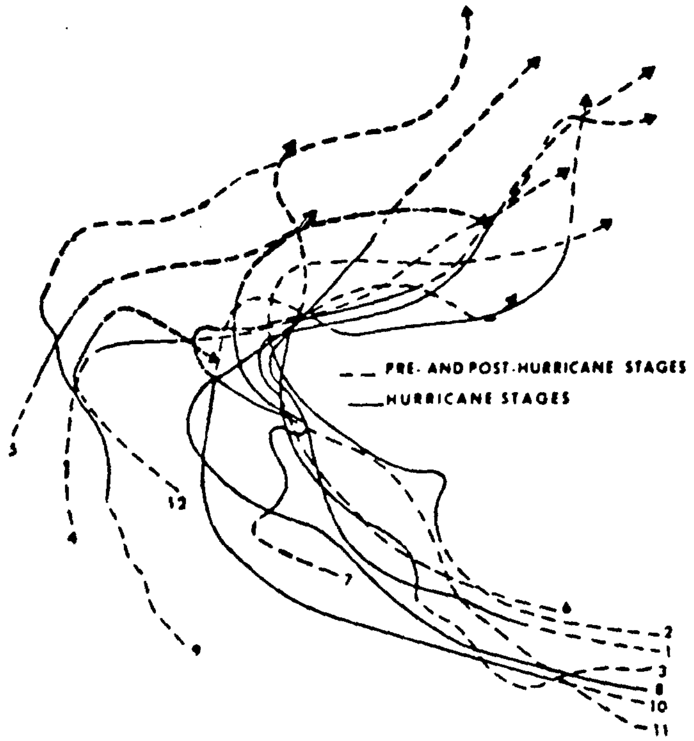


Figure 8. Incidence of Some Types of Natural Disasters

DEVASTATING NORTH ATLANTIC HURRICANE TRACKS
1955 - 1964



DATES OF HURRICANE	AREAS MOST AFFECTED	DATES OF HURRICANE	AREAS MOST AFFECTED
1. 1955, August 3-14 CONNIE	North Carolina	7. 1959, September 20- October 2 GRACIE	South Carolina to Virginia
2. 1955, August 7-21 DIANE	North Carolina to New England	8. 1960, August 29- September 13 DONNA	Florida to New England
3. 1955, September 10-23 IONE	North Carolina	9. 1961, September 3-15 CARLA	Texas
4. 1956, September 21-30 FLOSSY	Louisiana to northern Florida	10. 1964, August 20- September [illegible] CLEO	Southern Florida, eastern Virginia
5. 1957, June 25-28 AUDREY	Texas to Alabama	11. 1964, August 28- September 16 DORA	Northeastern Florida, southern Georgia
6. 1958, September 21- October [illegible] HELENE	North Carolina	12. 1964, September 28- October [illegible] HILDA	Louisiana

Courtesy- NADWARN- ESSA 6

Figure 9. Devastating North Atlantic Hurricane Tracks 1955 - 1964

Added to this list are-
Betsy- August 27 to September 12, 1965- Port Sulphur, Louisiana
Beulah- September 5 to 22, 1967- Southern Texas
Camille- August 17, 1969- Gulf Coast Mississippi
Celia- July 30 to August 5, 1970- South Gulf Coast- Corpus Christi August 3, 1970

These hurricanes damaged both on shore and off shore oil production and to some extent the refining and natural gas facilities of the area.

Figure 10. Carla's power was called equal to many megatons of atomic weapons.

Source; MP-22 Hurricane Carla OCD

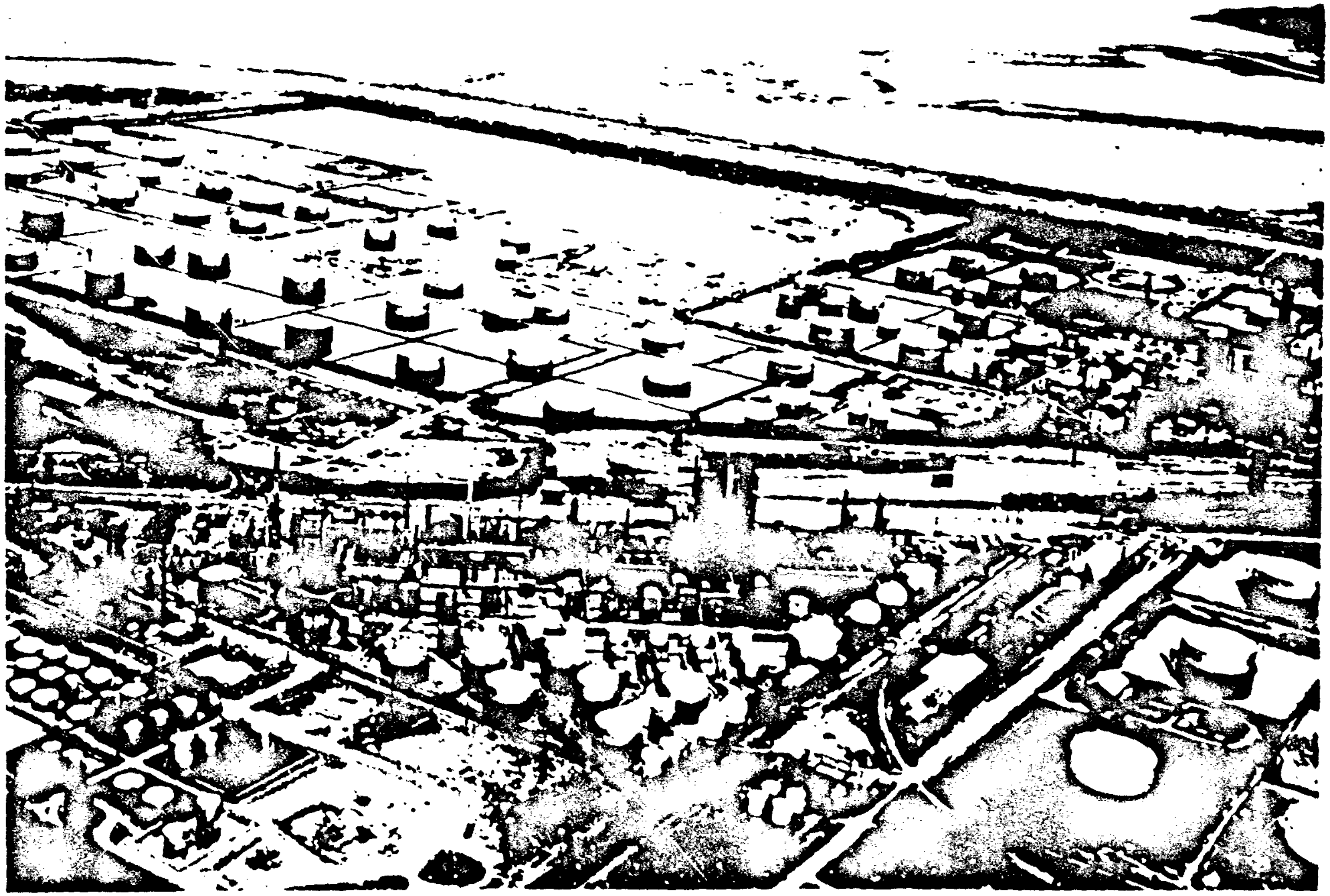


Figure 11. Texas City oil refineries were among those suffering heavy damage. City officials said that Carla caused more property damage than the 1947 explosion of ships at the dock.

Souce; MP-22 Hurricane Carla OCD

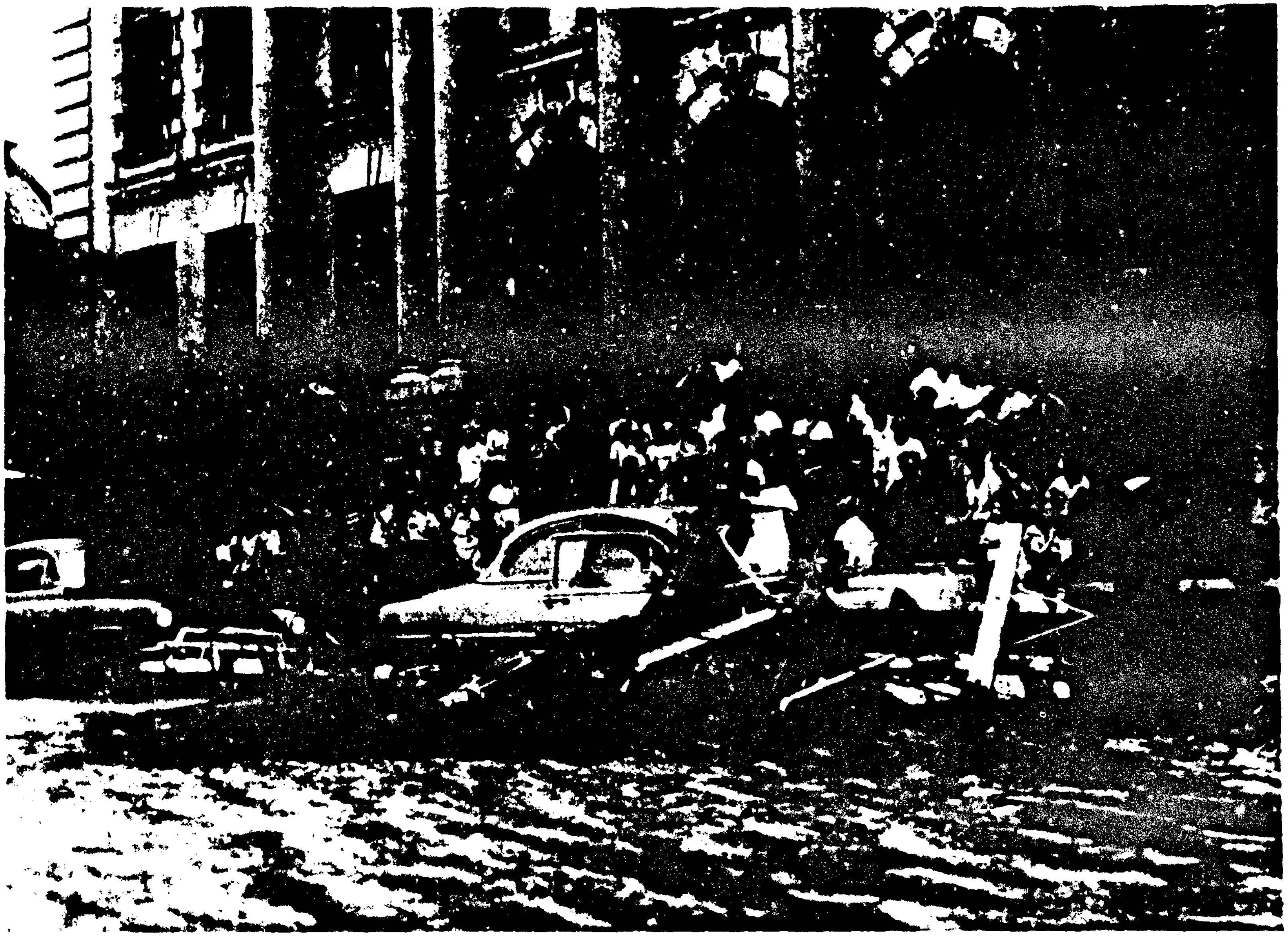


Figure 12. Twelve hundred Galveston residents survived the hurricane in the courthouse, although they had no cooking facilities and only minimum toilet facilities.

Table 9. Months When North Atlantic Hurricanes Occur to 1966

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Tropical Storms and Hurricanes	0	1	1	0	10	42	46	144	218	147	29	4	842
Hurricanes	0	0	1	0	2	17	26	106	142	70	12	2	378

Table 10. Loss of Life and Damage Estimates from North Atlantic Tropical Cyclones [1915-64]

Year	Loss of life in United States	Damage in United States 1 (millions of dollars)	Loss of Life in all areas including United States	Damage in all areas including United States (millions of dollars)
1915	550	63.0	n.a.	n.a.
1916	107	33.3	n.a.	n.a.
1917	5	0.2	n.a.	n.a.
1918	34	5.0	n.a.	n.a.
1919	287	22.0	n.a.	n.a.
1920	2	3.0	n.a.	n.a.
1921	5	3.0	n.a.	n.a.
1922	0	0	n.a.	n.a.
1923	0	Minor	n.a.	n.a.
1924	2	Minor	n.a.	n.a.
1925	6	Minor	n.a.	n.a.
1926	269	106.5	n.a.	n.a.
1927	0	0	n.a.	n.a.
1928	1,836	25.0	n.a.	n.a.
1929	3	0.7	n.a.	n.a.
1930	0	Minor	n.a.	n.a.
1931	0	0	n.a.	n.a.
1932	0	0	n.a.	n.a.
1933	63	46.7	n.a.	n.a.
1934	17	4.8	n.a.	n.a.
1935	414	11.5	n.a.	n.a.
1936	9	2.3	n.a.	n.a.
1937	0	Minor	n.a.	n.a.
1938	600	300.2	n.a.	n.a.
1939	3	Minor	n.a.	n.a.
1940	51	4.7	n.a.	n.a.
1941	10	7.7	n.a.	n.a.
1942	8	27.1	17	31.1
1943	16	16.8	19	16.8
1944	64	165.0	1,076	202.0
1945	7	80.1	29	80.1
1946	0	5.2	5	5.2
1947	53	135.8	76	135.8
1948	3	18.4	24	24.4
1949	4	58.8	4	59.8
1950	19	35.9	27	36.9
1951	0	2.0	244	25.0
1952	3	2.8	16	3.8
1953	2	6.2	3	6.1
1954	193	755.5	1,518	1,135.0
1955	218	984.5	1,516	1,251.5
1956	19	26.5	74	64.2
1957	395	152.1	475	+152.0
1958	2	11.2	42	+11.7
1959	23	23.1	56	+23.1
1960	65	370.4	180	379.6
1961	46	331.0	345	891.3
1962	3	1.1	4	+1.1
1963	10	18.0	7,203	542.9
1964	49	515.2	266	601.5
Total	5,475	4,380.3	*13,219	+5,480.9
Average	110	87.6	575	++238.3

[1]Note.—These are estimates only and have not been adjusted for changing dollar values.

*Cleo, Dora, Hilda and Betsy add 118 lives lost and almost countless property damage.

Hurricanes are accompanied by a relatively low barometric pressure, the lowest reported being measured in Lower Matecumbe Key, Florida, September 2, 1935.[9] A measurement of 26.35 (892 millibars) was observed, about 3½ inches below standard atmospheric pressure (about 1.7 psi below normal pressure). Plants located in areas frequented by hurricanes need to consider negative pressure when planning any new construction. See Figures 13 and 14.

Extra strength built into a plant for hurricane protection does a twofold job; it protects for excessive wind velocities furnished by nature, and it protects for excessive wind velocities created by explosions.

RECOMMENDATIONS

Many items of plant preparation for hurricane protection could also apply to nuclear blast preparation.[11]

The following is a partial list of pre-hurricane preparations:

- Provide Protection for Personnel
- Fill Empty or Partially Empty Tanks
- Execute Rapid Shutdown Procedure if Warranted
- Give Special Handling to all Electrical Equipment If power is interrupted, see that the main switch stays off until all workers are warned that the lines are "hot"
- Arrange for Emergency Water Supply for Fire Fighting, Equipment, Cooling and Drinking
- Adjust Guy Cables, Secure Gable Clamps, Check "Dead Men", and Piers and Nuts on Anchor Bolts
- Trailers and portable buildings must be tied down-they roll in the wind
- Remove Loose Equipment, Drums, Waste and Materials that Might Become Flying Projectiles
- Protect Foundation Against Undermining by wind driven water.
- Where Possible, Protect Equipment from High Water

This is only a minimum list for many other items peculiar to each plant are sure to need consideration.

Structures built in areas of potentially high winds should be capable of withstanding winds of at least 200 miles per hour and be located in excess of 30 feet above normal high tide if near open water. Estimated wind velocity in recent hurricanes have exceeded 200 m.p.h.

Tornadoes- The most violent of all atmospheric disturbances is the tornado. The forces developed, even in a small one, are almost beyond belief: wind velocities so high that blowing straw can develop the piercing strength of a bullet; blowing sticks as large as several inches across can be propelled with a force sufficient to drive them through tree trunks, to say nothing of what happens to the stuff from a junk yard or auto wrecking establishment. Of course, the winds of a tornado alone are almost immeasurably destructive, but the blowing and exploding debris associated with this attack of nature makes one's presence in the area almost as dangerous as being in "no man's land" on a battlefield. See Figure 15.

Approximately 10,000 people have been killed by tornadoes since the start of official records in 1916. In the United States, an average of 263 reported ground-touching "twisters" are recorded a year, accompanied by the death of an average of 194 persons each year. Table 11 shows the actual reported loss of life each year since 1916. Some tornadoes occurring away from communities may not have been counted. Also, only those that hit the ground are recorded; those in the air are classified as funnel shaped clouds.

Property loss is almost beyond accurate estimate. The best guess available indicates that at least $40,000,000 loss per year is a conservative value. In some years, the losses have been almost beyond any satisfactory measurement, exceeding several hundred million dollars, and added to this is the value of lost production, valuable records, and community discouragement. Industry has not been spared; serious damage has put many companies completely out of business.

A tornado with a circular wind motion quite like that of a hurricane is a much smaller, tighter, and much faster movement of air. In relatively small tornadoes, winds of over 200 miles per hour have been observed; larger ones have winds in excess of 500 miles per hour, as estimated from structural damage.[11] Such winds are in the order of those expected in areas of nuclear blast.[12] Since most wind guages blow off the scale of 115 to 120 miles per hour or blow even off of their supports, estimates of tornado wind velocities are made by an investigation of the structural damage done to buildings and industrial equipment. They are far in excess of that measured in the hurricane winds shown in Figure 14. It is often the case that anemometer cups are mounted on too flimsy supporting structure to withstand severe winds.

While the average tornado is only 100 to 300 yards in diameter, some have cut a mile wide swath. The average length of travel is 4 miles, but storms leaving 50 miles of wreckage behind are common. A tornado on May 17, 1917, travelled ?93 miles across Illinois and lasted 7 hours 20 minutes. The forward travel of a tornado averages from 25 to 40 miles per hour. However, some have moved at a rate of 68 miles per hour.[13] Tornadoes usually travel from southwest to northeast except those associated with hurricanes; these move easterly.

11 Factory Special Report "Now's the Time to Prepare for Hurricanes" Factory Management and Maintenance, Plant Operation Library No. 159 McGraw-Hill Publishing Company, August 1956

12 Glasstone, Samuel "The Effects of Nuclear Weapons" U. S. Department of Defense, U. S. Atomic Energy Commission, April 1962 page 87

13 U. S. Department of Commerce "Tornado Preparedness Planning" Environmental Science Services Administration, Weather Bureau, March 1968, page 25

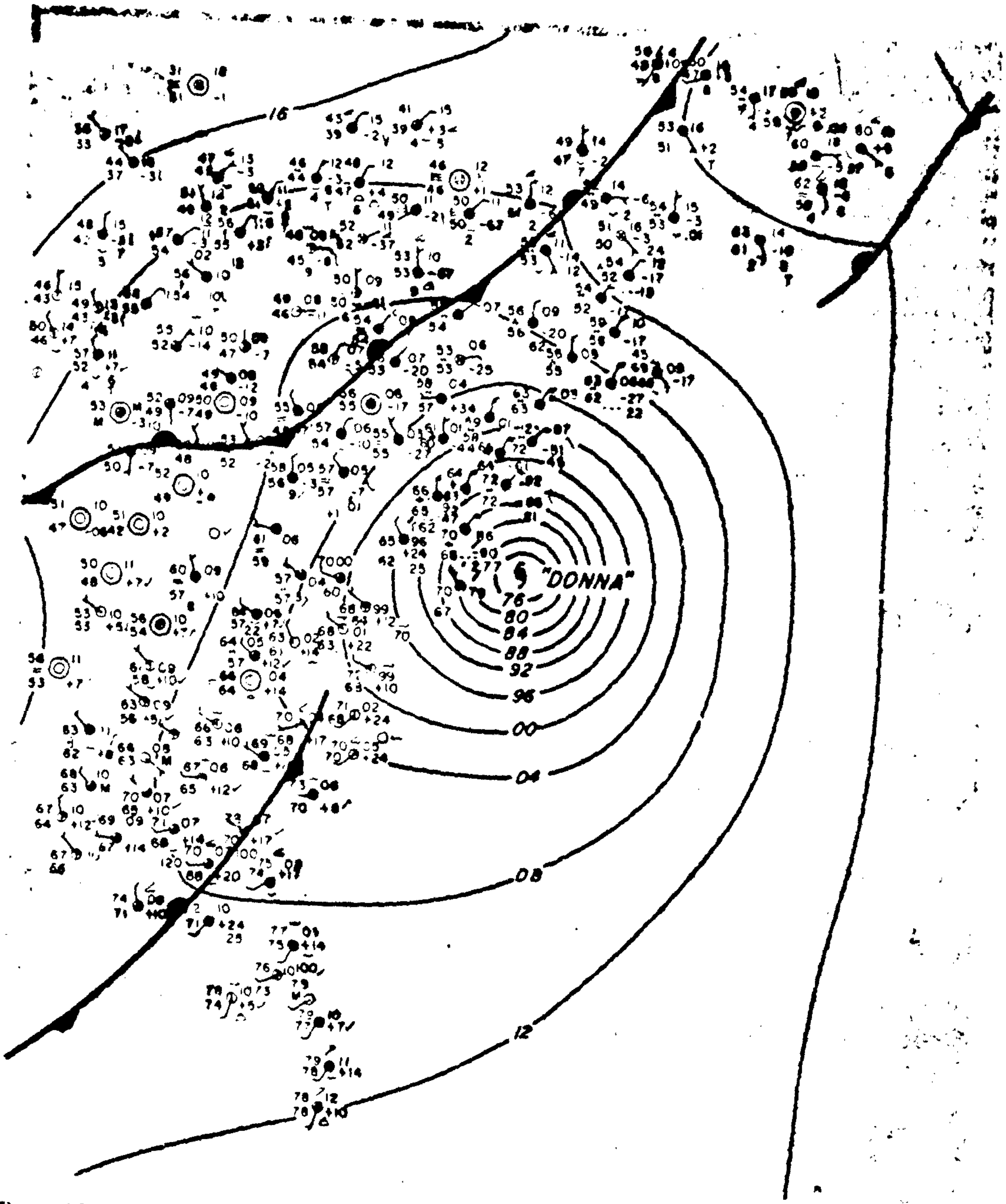


Figure 13. Hurricane "Donna" on the surface weather chart, 1200 GMT, September 12, 1960.

Source: Aviation Weather- U.S. Dept. of Commerce, FAA, Wash. D.C. 1965

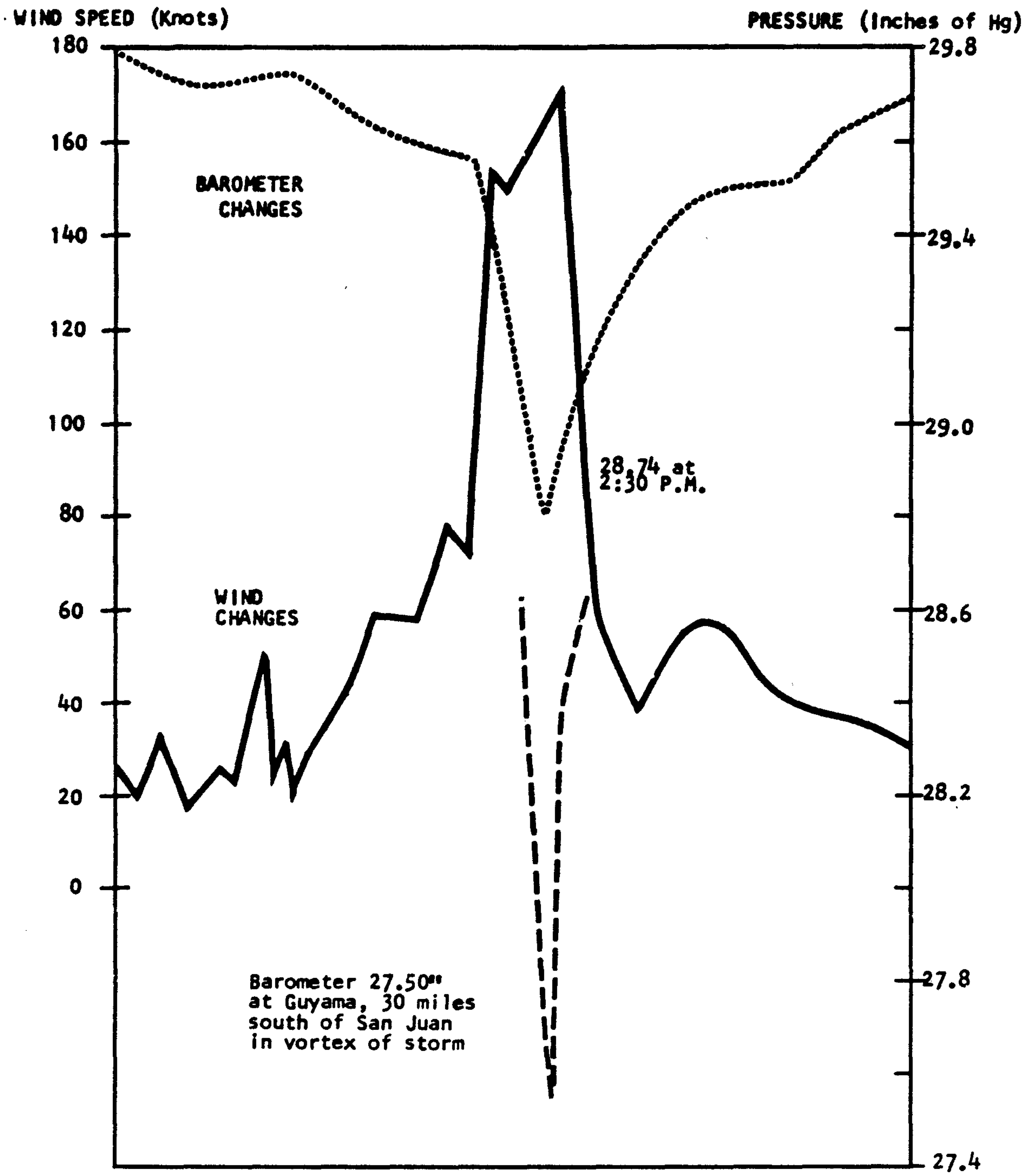
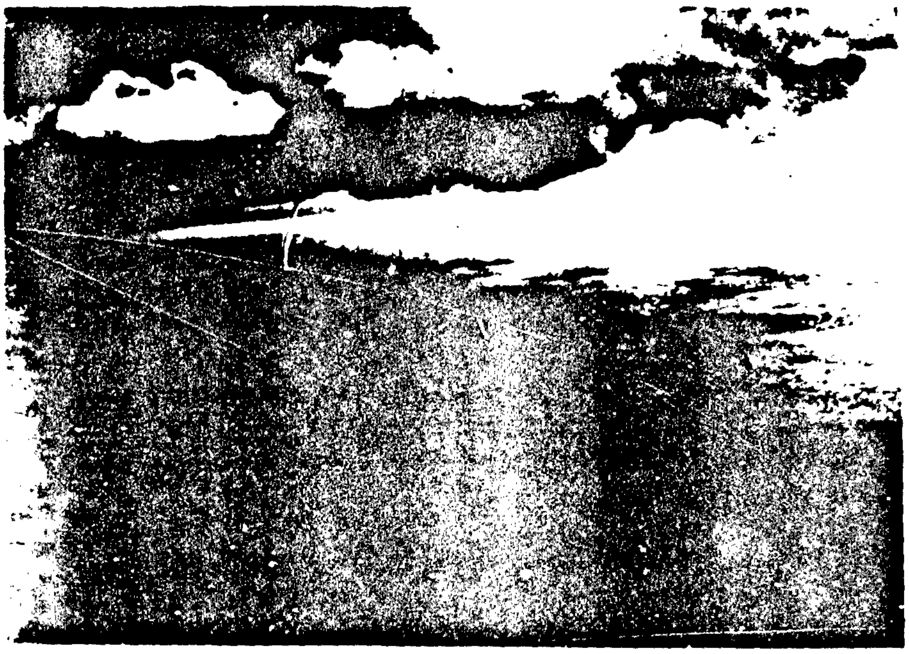


Figure 14

Source; Aviation Weather- U.S. Dept. of Commerce, FAA, Wash. D.C. 1965

A tornado



A waterspout

Figure 15. A tornado by land and a water spout by sea. Both are essentially the same. A waterspout could do substantial damage to offshore installations and bring torrential rains of water and fish on nearby shore installations.

Source: Essa Photo

Table 11[6]. The Annual Number of Tornadoes and Tornado Deaths Reported in the United States 1916-64

Year	Number of Tornadoes*	Deaths	Year	Number of Tornadoes*	Deaths
1916	90	150	1944	169	275
1917	121	509	1945	121	210
1918	81	135	1946	106	78
1919	64	206	1947	165	313
1920	87	493	1948	183	140
1921	105	202	1949	249	212
1922	108	135	1950	199	70
1923	102	109	1951	272	34
1924	130	376	1952	236	230
1925	119	794	1953	437	516
1926	111	144	1954	549	35
1927	163	540	1955	593	126
1928	203	92	1956	532	83
1929	197	274	1957	864	191
1930	192	179	1958	565	66
1931	94	36	1959	583	58
1932	151	394	1960	618	47
1933	258	362	1961	683	51
1934	147	47	1962	658	28
1935	180	70	1963	461	31
1936	151	552	1964	713	73
1937	147	29			
1938	213	183	Average	263	194
1939	152	87			
1940	124	65			
1941	118	53			
1942	167	384			
1943	152	58			

*Funnel clouds aloft, i.e. not touching the ground, and waterspouts (tornado over water) are not include.

[6]A Proposed Nationwide Natural Disaster Warning System-op. cit. p. 26

A sultry, humid, unseasonably warm spring afternoon having a build-up of thunderstorm clouds, a south wind, and overriding cool air, sets the stage for the formation of a tornado. A large thunderstorm is usually the parent of these giant vacuum cleaners of nature, although all thunderstorms do not generate tornadoes. Twisting tentacles of whirling air reaching out ahead of a large cumulo-nimbus build-up, destroy much that they touch. The funnel shaped cloud is the classic shape, and there can be several of these hose-like vortices attached to any one cloud mass. A long squall line can extend across several counties or even across a large portion of a state. From these cloud complexes, tornadoes are born. Not all rainstorms have "twisters",[14] but most large cloud masses develop some whirls near their base that under proper atmospheric circumstances can become violent and destructive winds.

Hail and lightning frequently accompany the parent cloud of the tornado. Lightning[15] accompanying thunderstorms is known to develop 100 to 200 million volts. The return strokes to the cloud, the major components of the flash, develop peak currents ranging from 5,000 to 50,000 amperes. Such could seriously affect electrical equipment in a refinery unless properly protected. Flat masses of falling ice, six inches across, are commonly observed by those living in areas visited by tornadoes (called cyclones erroneously in some areas. A cyclone is a circular moving large non-violent air mass, a barometric low. Such atmospheric lows rotate counterclockwise in the United States and can cover an area as large as one or more states.)

The possible loss of life and the home and industrial damage that can be done by a tornado is of particular interest to the refiner or natural gas processing plant owners

14 Weather Bureau "It Looks Like a Tornado" Handbook for Tornado Network Observers, U. S. Department of Commerce, Washington, D. C. 1953

15 U. S. Department of Commerce "Aviation Weather" Federal Aviation Agency Flight Standards Service, Washington, D. C. 1956 page 104

and operators. The latter named group, dotting the natural gas and petroleum producing areas of the country, are sure to experience a tornado sooner or later because of their location in tornado country. Many have "enjoyed" several visits. Protection provisions are essential.

One of the most terrifying times of record occured late afternoon March 18, 1925. Portions of Missouri, Indiana, Illinois, Kentucky and Tennessee were visited by at least eight large tornadoes. One killed 689 people, injured 1,890, and did in excess of 10 million dollars property damage. The other seven added another 740 persons to the list of that afternoon's work. On March 21, 1932, Alabama experienced a 5 million dollar visitor, leaving 268 citizens dead and 1,874 injured. The thirty-seven tornadoes that developed on Palm Sunday, April 11, 1965, killed 257 people, injured over 5,000, and caused many millions of dollars devastation. Six midwestern states were affected. This experience is still the subject of conversation in these areas. No matter how small the tornado, someone loses heavily; the large ones create a major disaster.

The map, Figure 16, shows the number and location of tornadoes occurring over a forty-five year period.[16] These are contoured to show their concentration. Figure 17 shows the frequency of tornadoes by month from 1953 to 1967.[17] The figures indicate that while the central plains areas of the country are quite familiar with tornadoes and are most often visited by them, substantial damage has occurred in all of the forty-eight conterminous states; the western mountainous states are relatively free of them. On January 7, 1969, winds of hurricane force in excess of 125 miles per hour, the peak that instruments were capable of recording, even ripped through Boulder, Colorado. The storm mangled telephone lines, wrecked homes, collapsed power lines, and left several dead and injured. Fifty thousand people were deprived of electric power and normal traffic was halted in much of the city.

As mentioned above, the wind velocities of a tornado are great, but the pressure within the tornado itself is considerably less than normal atmospheric pressure. It is a vacuum. Buildings enclosed within a tornado literally explode; the trapped air at normal pressure within the building exceeds in such cases the outside pressure and therefore blows out the walls. It takes a strongly built building to withstand such forces. Here again is a situation similar to forces experienced during bombing or during detonations within the plant. An unreinforced cement block building will not give adequate protection. Nuclear bomb explosions produce a strong wind velocity, then a negative pressure as the air fills back into the area disturbed by the blast. A tornado has a similar pressure relationship from its outer edge into its "eye".

A refinery or natural gas processing plant engulfed by a large tornado will be severely damaged, but by proper construction and planning, the smaller twisters can pass nearby doing relatively little damage. One of the most serious dangers is from flying debris, either from within the plant or from poor housekeeping of the neighbors. A dry shelter for personnel is a minimum requirement as protection from these projectiles and falling ice. While it may seem unrelated to the problem, it is also important that some substantial protection be available at the worker's home for his family so that he might stay on the job, in case of a warning, knowing that his family is as safe as he is. It is not uncommon for workers to dash home during a tornado alert, hoping to protect their families. This causes highway congestion and a sudden loss of manpower. In the so-called area of "tornado alley", the application of shelter designs worked out by Civil Defense could result in safer buildings and greater protection of personnel or families.

Drag-sensitive structures caught in or near the tornado's path, unless strongly constructed and adequately anchored down, can be death traps for personnel, as can pressure-sensitive structures of weak construction. Refinery control houses, switch gear houses, and other electrical equipment buildings, cooling towers, and poorly anchored pipe lines, all of primary importance to continued plant operation, are areas of vulnerability. A recent trend to build stronger control houses discussed in Chapter VII is correcting a part of the problem.

In areas of "soft" soil conditions such as former lake beds, filled areas, river sand where a well anchored foundation is not possible, it may be of advantage to use the pile cluster type pillar construction now used for modern hurricane protection in the Texas-Louisiana Gulf Coast plants. In swamp conditions of Louisiana and Texas, clusters of 250 foot long (or longer) steel and cement expanded foot piles are set and used for foundation supports. Four-inch (4 in.) or larger steel pins or bolts fasten the capping structure to the piling. Such construction limits the tendency for strong wind and water to get under the foundation slabs and overturn towers or other structures. This type foundation serves well in tornado areas where dead loads may become live loads during a storm. Extra strength anchor bolts are needed under these adverse conditions. In unusually strong wind calculations, the shearing as well as overturning forces must be given full attention. It is important that wind driven water not undermine a foundation or slab. There is greater damage of this in hurricanes.

RECOMMENDATIONS

The suggested procedures discussed under the topic of hurricanes apply directly to tornado protection. While the area of damage is not as great as with hurricanes, the intensity of the action in a tornado's path is usually greater. Those responsible for plant protection and operation should:

1. Become acquainted with the Natural Disaster Warning System and become allied to it.
2. Use local radio and Civil Defense warning facilities.
3. Have observers posted at vantage points to give warning of the direction of tornado travel in case of an alert.

16 U. S. Department of Commerce "Tornado Preparedness Planning" op. cit. page 28.

17 U. S. Department of Commerce "Aviation Weather" op cit. page 112

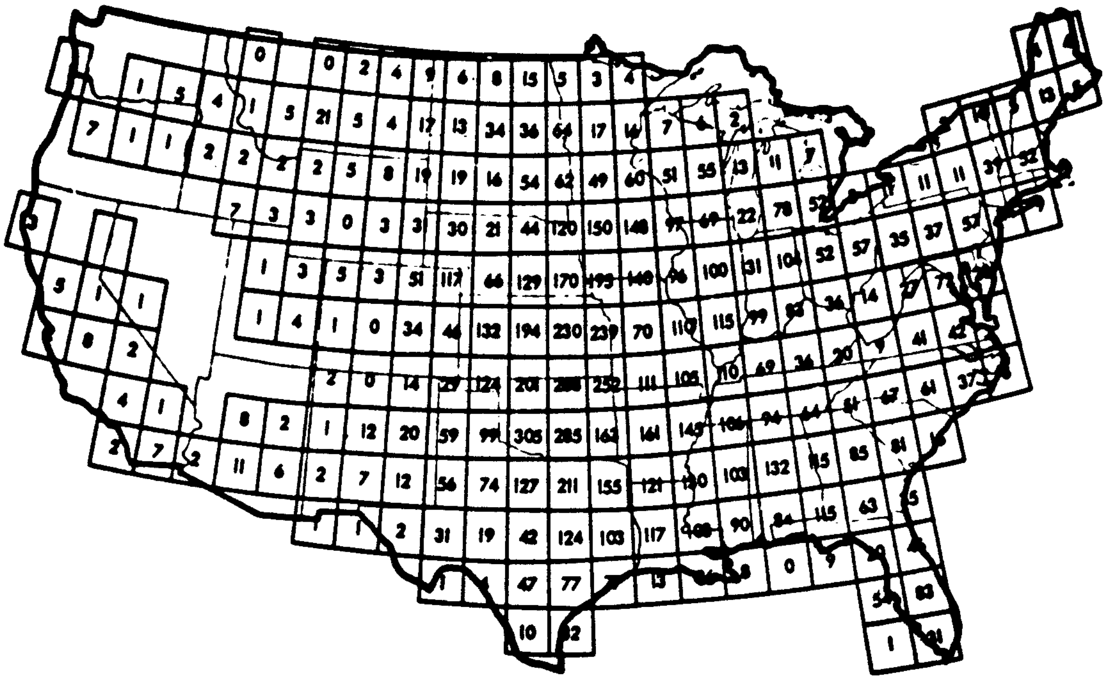


Figure a Number of Tornadoes Reported in a 45 Year Period, (2° squares), Overlaying a Map of the Industrial Counties of the United States

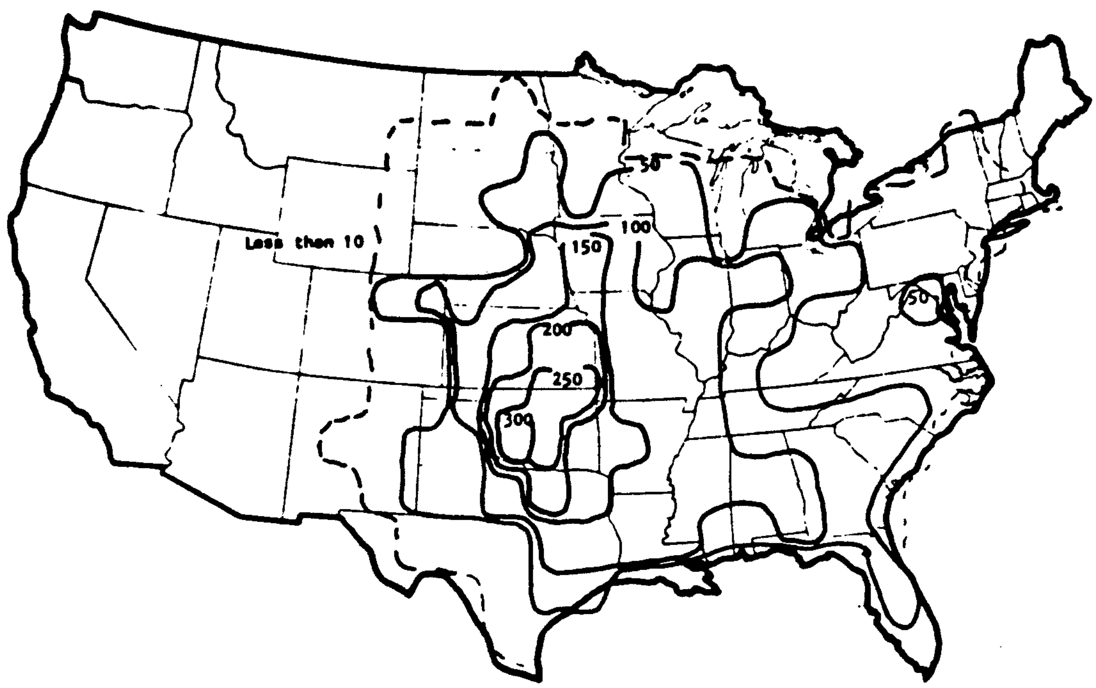
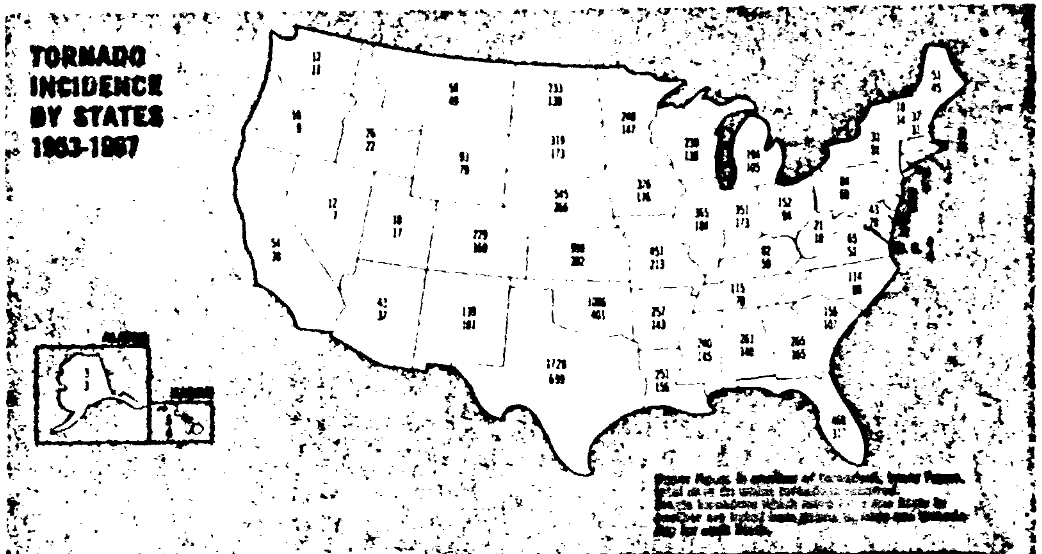


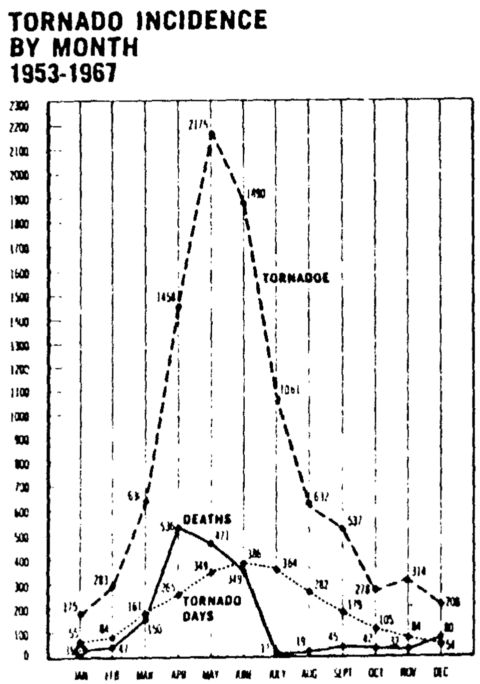
Figure b Contours of Data in Figure 16a

Figure 16. Tornado Frequency in the U.S.

From 1916 through 1952, fewer than 300 tornadoes were reported in any one year. In 1953, when the Weather Bureau initiated its tornado forecasting effort, more than 437 tornadoes were observed and reported, beginning the first period of reliable statistical history. Since 1953, partly through improved equipment and techniques, partly through increasing public participation, essentially complete tornado records have been available. This publication summarizes tornado incidence for the period 1953-1967.

More tornadoes occurred in 1967 than in any prior year of record for the United States. In 44 States, 912 tornadoes killed 116 persons and caused property damage in the millions of dollars. Tornadoes were unusually numerous in January, September, and December. Hurricane Beulah spawned 115 tornadoes in Texas on September 19-23, 1967, setting a new record for any hurricane. Only six States had no tornadoes in 1967: Alaska, Connecticut, Montana, Rhode Island, Vermont, and Washington.





Source: Essa-Tornadoes

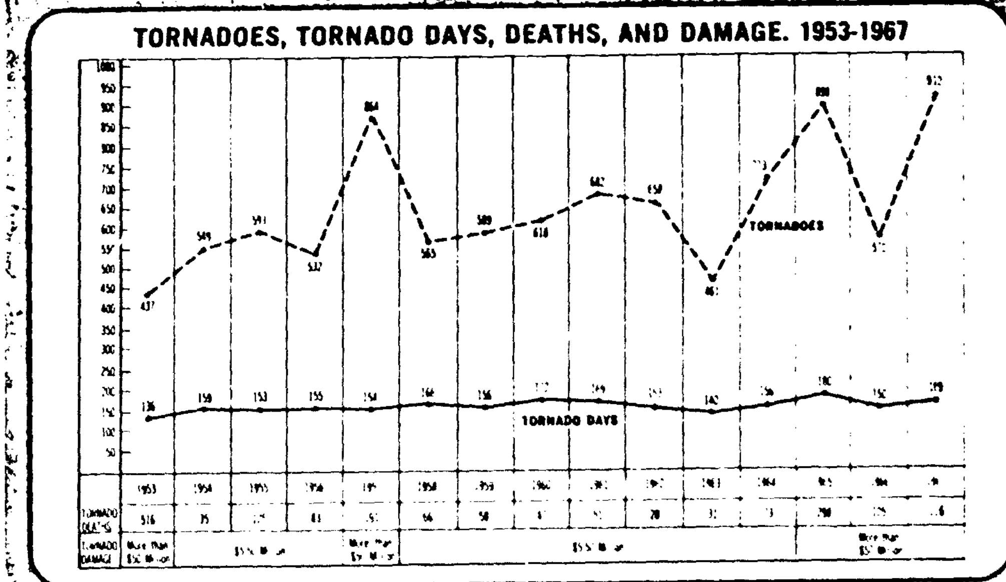


Figure 17

4. Have a well prepared disaster plan including a safeguard of records, drawings, and specifications. This would include having either hard copy or microfilm records and valuable documents storaged in disaster-free vaults. A check list of "what to do" is valuable to have before it is needed; also, who is to do it and how, should be well understood by each operator.

5. Have clearly assigned disaster responsibilities among key personnel.

6. Have portable and mobile communication system, including a generous supply of "walkie-talkies".

7. Have an emergency disaster security plan, a mutual aid plan, and a self contained plan in case civil, fire, and police services become overtaxed because of the extent of the disaster.

8. Plan buildings without "air foil" roofs, and strongly tie down all structures that tend to "take off" in a high wind.

9. Plan to handle excess flood water.

10. Provide well planned shelters free from the dangers of accumulating toxic or explosive heavier than air gases and flood water. Such buildings should be constructed according to Civil Defense specifications and standards so as to serve also when needed during an enemy attack.

11. Have a generous supply of critical parts so as to avoid long periods of shutdown.

12. Clamp down disposal cans and other objects that can be converted into projectiles by high wind.

This is by no means a complete list, since much is available on personnel and plant protection through Civil Defense sources. These should be acquired and applied to the needs of your industry. The handbook "Tornado Preparedness Planning" cited above (footnote 13) discusses this subject further.

Earthquakes-[18] Industry is vitally interested in earthquakes because of the misalignment effects of equipment, the rupturing of pipe connections, the destruction of structures not properly designed for earth tremors, and the injury to people. Closely related landslides and rock slides often create even greater and more frequent industrial damage than major seismic waves. These slides are not always related to earth faulting as are earthquakes.

Building damage by earthquakes results from the shock waves moving in the foundation rocks. These waves are generated, in nature, by movement along the fault planes which separate large blocks of rock within the earth. Shock waves coming to the surface bounce buildings- similar to the action of the end ball of a number of touching billiard balls when the opposite end of the line of balls is hit. Buildings need to be constructed so as to withstand side thrusts in their foundations. See Figure 18.

Tidal waves, known also as Tsunamis, are the direct result of earthquakes or volcanoes originating on the ocean floor. Forty-eight have occurred in the Pacific Ocean since 1946, and seven of them caused damage in the United States. The sudden high water caused the death of several hundred persons in the United States and serious loss of property to industry located near the ocean. The seiches of the Great Lakes, high water caused when a southeastern wind reaches 65 miles per hour velocity, do similar damage to industry near lake fronts. These are not related to earthquakes but to wind velocity alone. There have been ten on Lake Michigan since 1954.

The disaster map, Figure 8, indicates that most earthquakes are related to the geologically active area of the country, i.e. the western and coastal mountain areas. Few weeks go by without some large tremors, "tremblors", being measured in the industrial areas of the west. All of California and Nevada can expect seismic action at any time, especially in the areas of large faults. All consolidated rock is fractured so as to cause joint planes. Any movement along these joint planes creates faults and at the same time generates seismic waves that cause movement at the surface. Faulted areas are zones and are not usually sharp lines; thus from a major fault, many smaller faults parallel and radiate out from the main area.

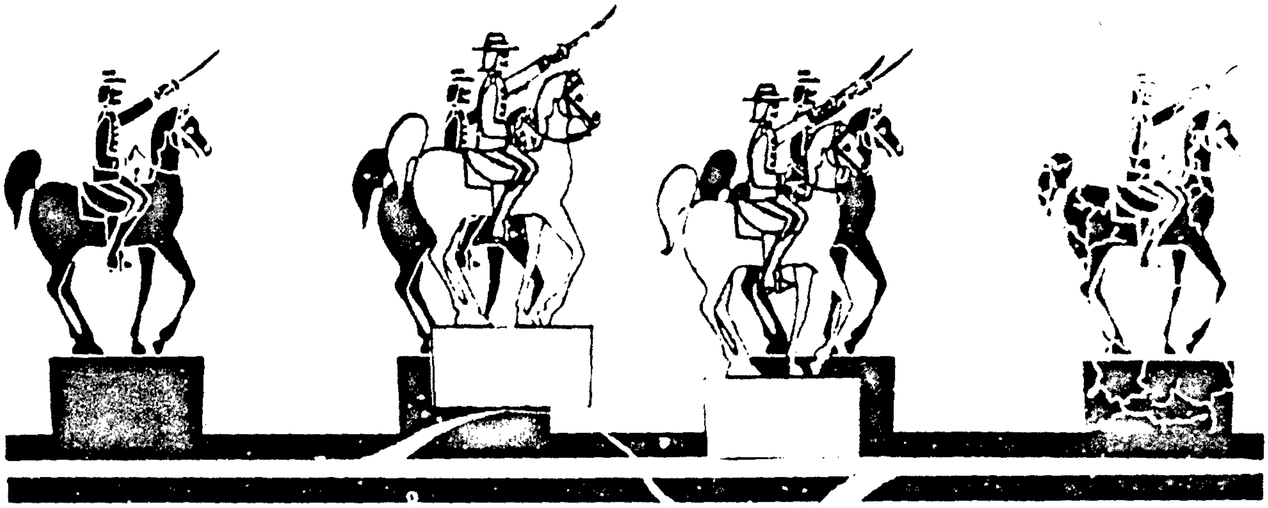
The recent Alaskan earthquake made history. South central Alaska was stunned on Good Friday, March 27, 1964, at 5:36 P.M. by one of the strongest earthquakes of record. It reached 8.4 plus on the Richter scale according to a report by the Office of Civil Defense.[19] In this instance the mild starting vibrations built steadily until soon houses were pitching and rocking; buildings swayed 10 to 12 feet at their tops; some sank 20 to 30 feet as blocks of rock became displaced. Homes built on hills were carried away by sliding earth, a secondary effect of the tremors in Alaska. The 40 to 50 foot diameter petroleum product storage tanks developed wrinkles and bulging near their bases demonstrating that a specially designed tank is needed for storage use in earthquake areas. The Alaskan earthquake damage was estimated at 583 million dollars and with 82 known dead, 33 missing, and many serious injuries. The tidal wave, a secondary effect, raced down the Pacific coastline, struck with great violence in Washington, Oregon, and California where some people were trapped by the high water. While Alaska is about twice the size of Texas, its population is only 250,000. Had this disaster occurred in a highly industrialized area, the damage could have created economic havoc in the area. A number of large refineries occur in areas of known active faults.

The well-known San Francisco earthquake in 1906 caused the death of at least 700 people and resulted in a property loss of 1.6 billion of 1906 dollars. The fire storm that followed the shock burned much of the city. Many landslides also occurred.

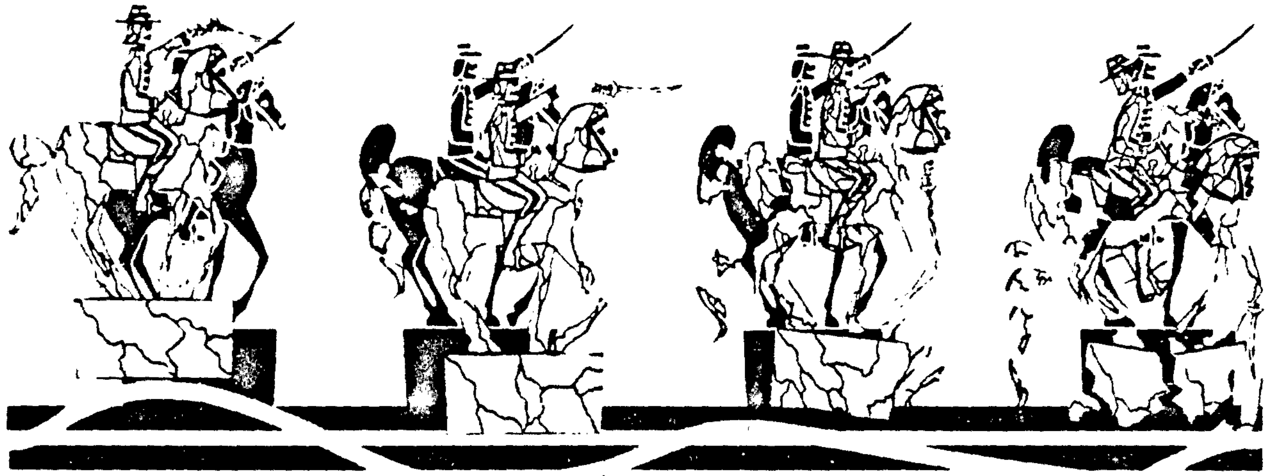
The western part of the country cannot lay exclusive claim to earthquakes. A great earthquake occurred in Charleston, South Carolina, August 31, 1886. At least 60 people were killed and property was extensively damaged. After shocks continued for over a year. The shock was even felt in Chicago, Illinois, and Boston, Massachusetts. One of the 20 greatest of the earthquakes affecting this country occurred in the Upper Mississippi Valley in 1811 where

18 U. S. Department of Commerce "Earthquakes, Information Bulletin" NEIC, ESSA, Vol. 1, No. 9, November 1967, and "Earthquakes" a 350-033, 1969

19 U. S. Department of Defense "The Alaskan Earthquake" Office of Civil Defense, May 1964



The compressional phase of a P-wave train displaces the statue's pedestal away from the earthquake parallel to the direction of wave travel; the rarefactional phase dilates the ground, shifting the pedestal in the opposite direction.



Transverse S waves arrive and begin shaking the statue at right angles to the direction of wave travel, completing the destructive work begun a few seconds earlier

Figure 18. Rough Ride for a Man on Horseback

Source: ESSA - Earthquakes - Department of Commerce - 0-350-033 1969

considerable topography was changed. See Table 12 for others.

Although 90% of the seismic activity in this country centers in the western states, any area having known geological faults can expect activity, for earthquakes are the direct result of isostatic adjustments of large blocks of the earth. Movement of rock segments sets up shock waves. When the seismic waves reach the surface from their epicenter, buildings and structures are bounced. Money expended in *heavier or stronger alloy tie down bolts of structures* and *stronger and better designed foundations* usually are good investments in areas where earthquakes occur.

Refineries built in mountainous and even hilly country need to take geological as well as soil conditions into serious account. The cutting through of a road along the side of a hill has on several occasions caused a whole hilltop to become unstable and to slide down when dipping rock surfaces were wet by melting snow and spring rains. The construction of the road along the western side of Lake Superior in Minnesota is a typical example. Here, the blasting of a rock ledge for the lake shore drive highway removed rocks that wedged and held back a mountain of rock that dipped toward the lake. Heavy steel and concrete pins were needed eventually to "nail" the rock layers down, - a very costly operation.

Tank farms located in a hilly area could wipe out a refinery if the foundations of the tanks were shifted or the lines broken. Pile driving, blasting, earth moving on a large scale and frequent moving of heavy equipment can cause areas to shift that have for years been considered stable. The making of the Panama Channel illustrates this point. The removal of earth in "the ditch" caused subsidence from the hill area to move, filling in the cut faster than it was made. The impounding of a large lake can inundate fault zones, wetting the gouge between rock layers and eventually permitting earth movement. Such geologically unstable areas could also be in danger from earth movements in case of ground blast of a nuclear weapon.

Much study is being given to earthquake prediction. Studies of geomagnetic variations along fault blocks offer some hope of being able to obtain lead time in the warning of impending trouble. An array of magnetometers, which measure changes in the earth-magnetic field, located by staff members of Stanford University along the San Andreas fault of California, have shown interesting data. See Figure 19. From December 1965 to October 1966, small changes in the geomagnetic field were observed several hours prior to actual creep occurrence along the fault. On April 18, 1967, a local decrease in magnetic field of the earth was observed simultaneously on four instruments positioned over a 25 Km. span along the fault. Creep displacement of 4 mm. occurred 16 hrs. after the magnetic event, and a series of earthquakes, the largest not exceeding Richter magnitude 3.6, followed April 20-22, 1967.[18]

Refinery construction should be preceded by careful geological studies of the foundation rocks and soil as well as the water drainage environment to avoid possible disaster. Much work is available on the subject.[20 & 21] There is a tendency for economic reasons to build higher and higher structures and to "stretch" the limits of the National and the Los Angeles Building Codes to their very maximum.[22] All building codes should be considered minimum standards. It may not be economically possible to build for a major earthquake, but in areas frequented by earthquakes, it is well to have an extra factor of safety built into a multimillion dollar installation since it is known that sooner or later a major tremor will occur. From a national defense viewpoint, structures securely fastened to heavy foundations are better constructed to withstand the stresses created by nuclear attack. This was dramatically demonstrated at Nagasaki and Hiroshima, where earthquake construction was common when they, were hit by approximately 20 KT bombs. Buildings built for earthquake resistance withstood the blasts better than others.

Much study is constantly being given to seismic problems and their relationship to industrial endeavor. New types of construction are always under study. The Earthquake Engineering Research Institute of San Francisco is one of

Table 12. Major U.S. Earthquakes and Loss of Life

Year	Place	Lives Lost
1811	New Madrid, Missouri	Several
1812	San Juan Capistrani, California	40
1868	Hayward, California	30
1872	Owens Valley, California	27
1886	Charleston, South Carolina	60
1899	San Jacinto, California	6
1906	San Francisco, California	700
1915	Imperial Valley, California	6
1918	Puerto Rico (killed by sea wave from earthquake in Mona Passage)	116
1925	Santa Barbara, California	13
1933	Long Beach, California	120
1934	Kosmo, Utah	2
1935	Helena, Montana	4
1940	Imperial Valley, California	9
1946	Hawaiian Islands (killed by sea wave from earthquake in Aleutian Islands)	173
1949	Puget Sound, Washington	8
1952	Kern County, California	13
1954	Eureka-Arcata, California	1
1955	Oakland, California	1
1958	Khantaak Island and Lituya Bay, Alaska	5
1959	Hebgen Lake, Montana	28
1960	Hilo, Hawaiian Islands (killed by sea wave from earthquake off the coast of Chile)	61
1964	Prince William Sound, Alaska (almost all deaths were along the Gulf of Alaska and west coast of United States from resulting sea wave)	156

18 Earthquake Information Bulletin, op. cit. page 3

20 State of California "Geology of Southern California" Division of Mines, Department of Mineral Resources, Bulletin 170, Vol. 1, 1954 Many other references are given in this bulletin.

21 Tectonic Map of the United States- American Association of Petroleum Geologists, Tulsa, Oklahoma

22 Los Angeles Orinance No. 100,347 amending Art. 1, Chapt. 9, Los Angeles Municipal Code, August 26, 1952

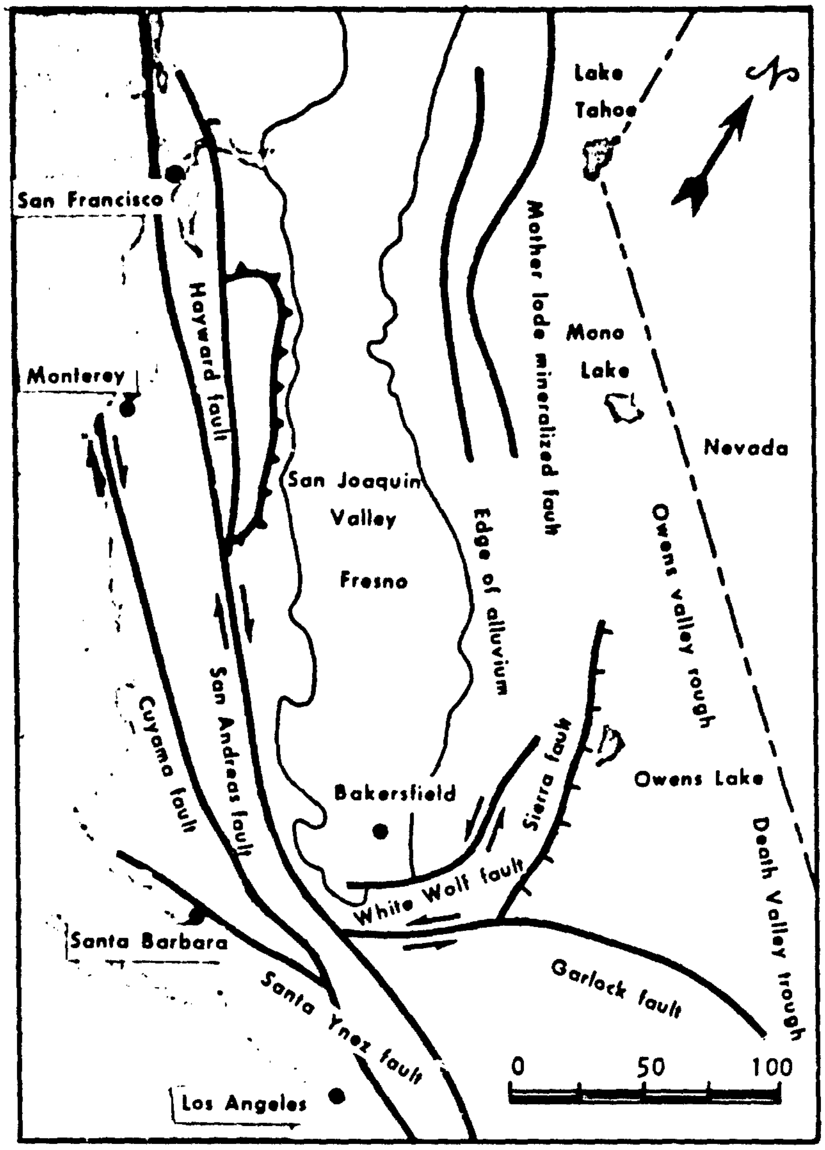


Figure 19. Map of part of California showing some of the faults. The San Andreas fault is outstanding

the groups contributing to this science. Their bibliography[23] is of help to those desiring further information.

Although earthquakes have not killed as many people in this country perhaps as hurricanes and tornadoes, the property loss is staggering. As faulted areas become more populated, one could expect a substantial increase in lost life during earthquakes. Italy, China, and Turkey have had earthquakes resulting in a great loss of life.

23 Hollis, Ed. P. "Bibliography of Engineering Seismology" Earthquake Engineering Research Institute, San Francisco, California 1961

RECOMMENDATIONS

When refineries and natural gasoline plants are to be built in areas known to be faulted, serious consideration needs to be given to such geological conditions and special designs used if warranted. National, state, and local codes should be considered only as a minimum specifications. Added structural and foundation strength built into a refinery could in time pay off handsomely in the event of a serious earth movement created by nature or by earth shock due to an explosion.

Pre-disaster planning of one's operation is needed so as to minimize property loss and loss of life. Check lists for nuclear defense preparation and post action recovery, available through the Office of Civil Defense, could be of great use before and after an earthquake experiences, for the problems of restoring operations should be almost identical. Some will be presented here in later chapters.

Storage tanks uphill from a refinery should be adequately diked and the diking drained away from the plant to avoid a downhill flow of burning oil. Plants in low areas should take precautions to avoid submersion in the event of a tidal wave. It should be recognized that the trend to stretch the height of refinery structures built in earthquake zones is injecting additional serious risk into an operation.

Keep well informed on earthquake activity in your area. The National Earthquake Information Center of ESSA, U. S. Department of Commerce, has a regular information service available to those needing it.

The stronger a foundation, the more durable the foundation bolts, the more shock resistant construction used, the better the structures will withstand bombardment or even explosions occurring within an installation.

Chapter IV

RISK SUSCEPTIBILITY DUE TO LOCATION - INDUSTRIAL RELATIONSHIPS

Interdependency on the Electric Industry

Outside of the supply of crude oil, dependency on commercial electric power stands out as a most vulnerable situation for the refiner.

Early Industry - Primitive industry was centered around a family group or tribe. It was almost entirely self-sufficient. Often the family needs were all that were provided. All power was manual or animal derived.

As specialization of skills between groups developed, the need for power became urgent. In early America, industry centered along the water falls in rivers because of the availability of the energy needed to run machines. The "fall line" or line of water falls of New England became important as a mechanical supplier of power.

Electricity revolutionized the situation and had much influence in the location or concentration of industry.

Electric Power - Although the water wheel as a prime mover has given way to the modern turbine generator, energy from hydraulic sources is still important. Energy from Niagara Falls or from great dams are but examples, but here again, power generation is located because of a hydraulic source, a water falls, a dam or a rapidly falling mountain stream. The length of power transmission lines and line losses increasing with mileage become considerations of economics. As steam generation developed, the supply of coal at first, and later, the availability of oil and gas, became factors in the choice of generating plant locations. The ease of transportation of coal, gas and oil changed the need for dependence on large generating plants located at hydraulic sources. Many local electric plants were built near the markets; the lines were short, - the plants, many. The availability of power has, in many cases, influenced the location of an industry. The recent establishment of nuclear powered electric generators which can operate anywhere offers even more flexibility as to the location of industry and power plants.

At present, almost 2000 electricity generating plants supply in excess of 950 billion kw-hrs. to domestic and industrial consumers each year.

A further reduction of dependence on large, far distant power generators results from the local use of small, sometimes portable, gas turbine and diesel powered generators. In many cities, apartment houses, office buildings and industry have installed for their use gas turbine and diesel generators as a prime standby measure. Some refineries are now self-sufficient as to electric power. Most utilities have portable units that can be moved into some emergency situations when there is a sudden localized demand. This dispersal of generation equipment is good defense.

The refining industry is dependent in most plants on electric power; the nearness of a generator is of strategic importance. See Figure 20. Each refinery complex should have a substantial amount of oil or gas operated auxiliary power so as to insure against complete failure of electric power from commercial sources. In time of man created or natural disaster or general power failure any source of auxilliary power, large or small, can become a tremendous asset to an industrial installation.

Great strides are made daily in the development of electrical energy by some 3000 or more utilities of the country. For quite a time, even within the memory of this generation, there existed the situation that each generating plant had its own relatively small area to serve. The type of power - whether direct or alternating current or 25, 50, or 60 cycle, 110 or 220 volt current -made little difference since all in that small area had to use what was available. Even until recently some older cities had one type power in the older sections or the business area and another for the industrial and residential areas. A local storm often cut off the power until lines could be repaired.

As the industrial and domestic demands for electricity grew, so did the electrical power utilities. And, as electricity became available and completely dependable, so has there been a great increase in the dependence of most industry on this type of energy. The story as to how the electric plants of the nation are now "looped" together is an interesting one and important to all industry. Standardization on 1300/440 stepped down to consumers' 120 volt, 60 cycle current has made this possible. The failure of a local power plant normally causes only a blink of the lights, since some plant far away automatically cuts into the line to absorb the local load. Standardization has also made rapid repair possible; extra crews borrowed from other areas can move in to a damaged system and work on it as though it were their own. As one executive put it, "As long as we have wire, we can get the power where we need it." See Figure 21.

The almost complete industrial dependence on electric power does make that industry a keystone in any modern civilization, and the electric industry is serving well. But, with strength there also develops weaknesses. Even though the electric power industry has made dependable power available under normal conditions, still there are times of power failure. *Sudden shutdowns of some industries are costly, particularly a refining or petrochemical plant!*

There is an interdependence back from the refinery to the utilities. Not all generators are hydro-electric or nuclear; a great many are dependent on petroleum or natural gas as their source of fuel. The entire petroleum industry then becomes a key industry as do also pipe line, surface and water transportation companies. They all form links in the chain of industry and in time of national emergency, there must be enough self-sufficiency on the part of all segments so as not to cause serious disruption of effort. This does not now exist. In time of disaster, the coordination of the interconnecting links becomes major problems. Modern industry is

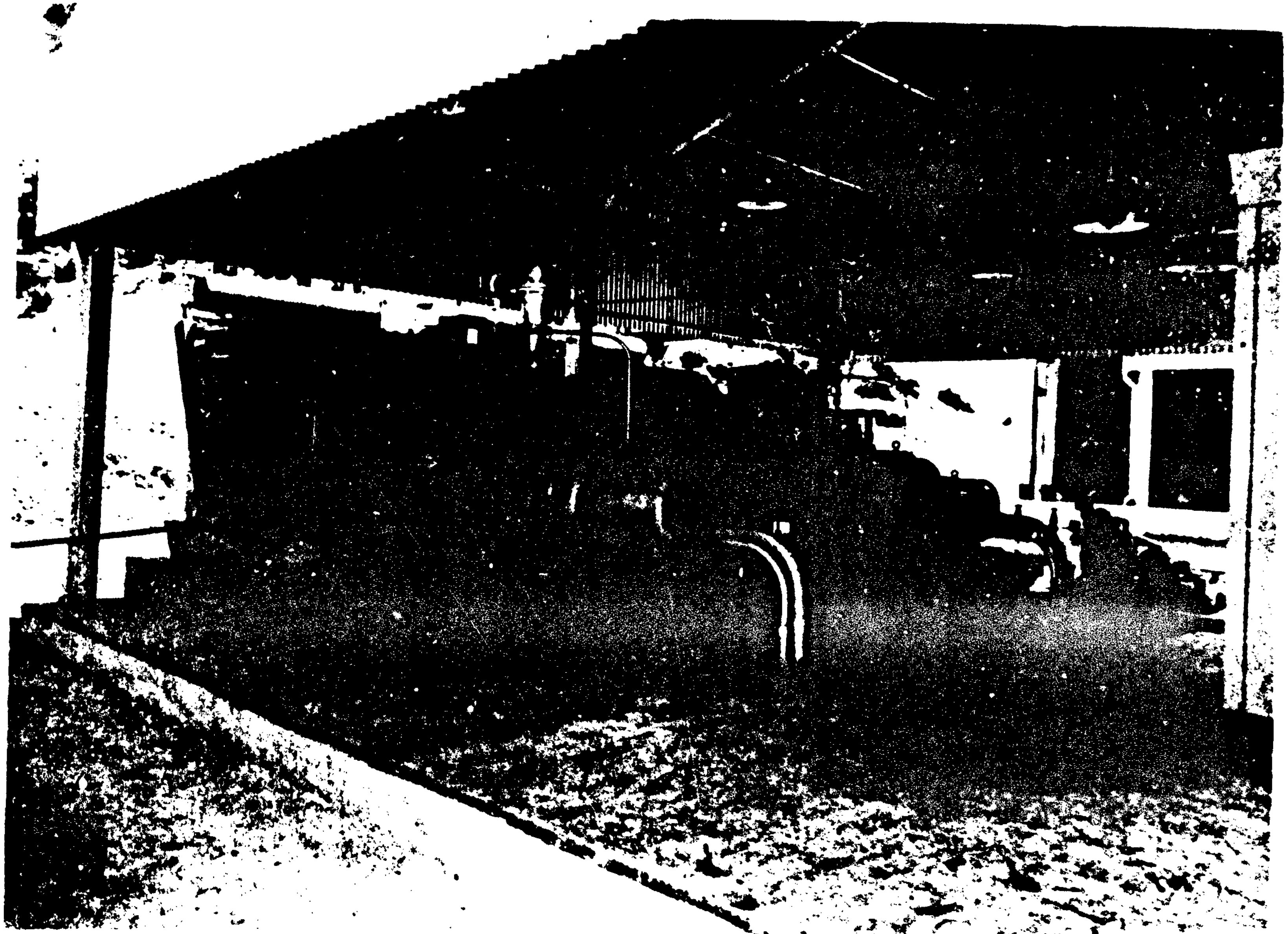


Figure 20. A 200kw Electric Plant. Marathon Oil Co. Iraan, Texas. Equipment 2 Caterpillar G 353 TA, 7:1CR-1200 RPM

Source: Caterpillar and Mustang Tractor and Equipment Co. Houston, Texas.

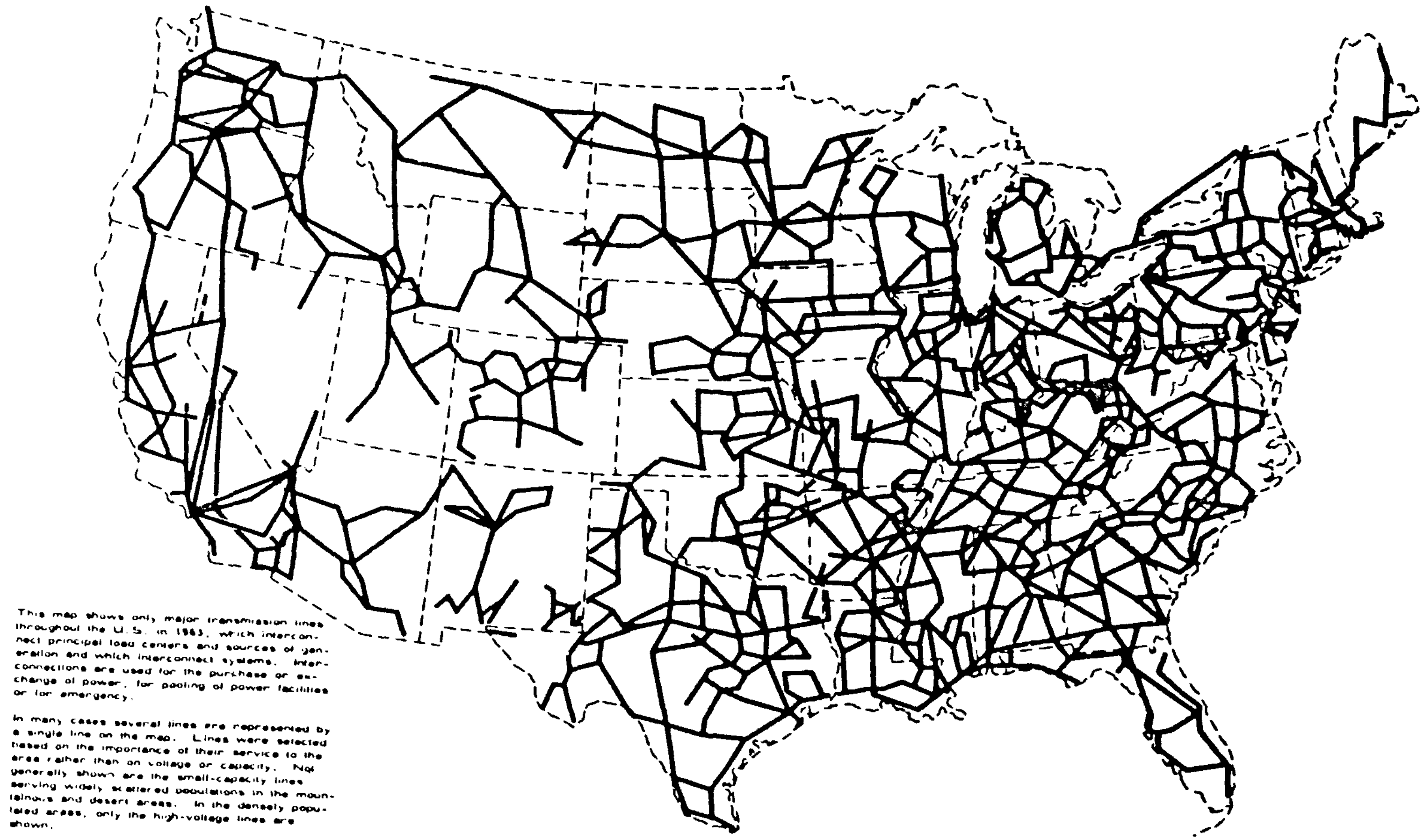


Figure 21. Major Electric Transmission Networks and Interconnections in the U.S.*

This map shows only major transmission lines throughout the U. S., which interconnect principal load centers and sources of generation and which interconnect systems. Interconnections are used for the purchase or exchange of power, for pooling of power facilities or for emergency.

In many cases several lines are represented by a single line on the map. Lines were selected based on the importance of their service to the area rather than on voltage or capacity. Not generally shown are the small-capacity lines serving widely scattered populations in the mountainous and desert areas. In the densely populated areas, only the high-voltage lines are shown.

*The 750 kv North-South Entertie added to original map.

as intertwined as a school of playing octopi; the perpetual motion of supply and demand in industry each supplyihg the other is continuous and unending. A major problem, therefore, in any consideration of plant continuity of operation is "what to do when the continuity of industry becomes interrupted - how long can I remain self-sufficient?"

A power outage is not limited to the occurrence of a disaster; even one of short duration often causes major problems in a refinery operation or petrochemical installation.* Even the "looping" of electric plants, while usually a great advantage, has at times created serious problems when the sudden failure of one plant threw an excessive load on the other plants in the "loop". The "blackout" of November 9, 1965, in the northeastern portion of the United States instantly revised the pattern of normal living habits of many people. A "domino effect" came into play. See Figure 22. First one, then another power plant in the "loop" failed. Elevators were stuck between floors, electric trains stopped, lights went out - all industry was instantly shut down. Electric appliances were useless; one couldn't even make a piece of toast. Soon automobiles were out of gasoline with no gasoline pumps to "fill them up". A few portable generators helped here and there. Matches, candles and flashlights suddenly became very important. For a while, people were deprived of modern necessities, a situation that would be common in time of war. Many new refineries are almost completely dependent on some outside source of electricity, and it is not uncommon to find even many of the plants buying 100% of their electric power. All industry can be caught by the "domino effect" of power failure.

*Further discussion in Survey of Electric Power Problems, Summer 1971, Report O.E.P., May 1971

The National Petroleum Council made a study of the effects of the power outage on the petroleum industry. This study was stimulated by the eastern experience of November 1965. The experiences of the outage could give a preview of what could happen in time of attack. [24]

The study was based on information previously acquired by the Council in a survey of 1961 and of 1963 - the latter entitled, "Chemical Manufacturing Facilities of the Petroleum and Natural Gas Industries", and included work of the U.S. Bureau of Mines, January 1, 1961, on crude oil charge capacity. Although the report is ten years old, the basic results of the study still apply.

The country was divided into areas corresponding to the defense regions of the Office of Emergency Planning, Office of Civil Defense and the Department of the Interior, Office of Oil and Gas (EPGA). See Figure 23. The divisions used, even though somewhat arbitrary, are important since the basis of the study corresponds to these defense regions.

24 National Petroleum Council "Impact of Electric Power Outages on Petroleum Industry" 1966

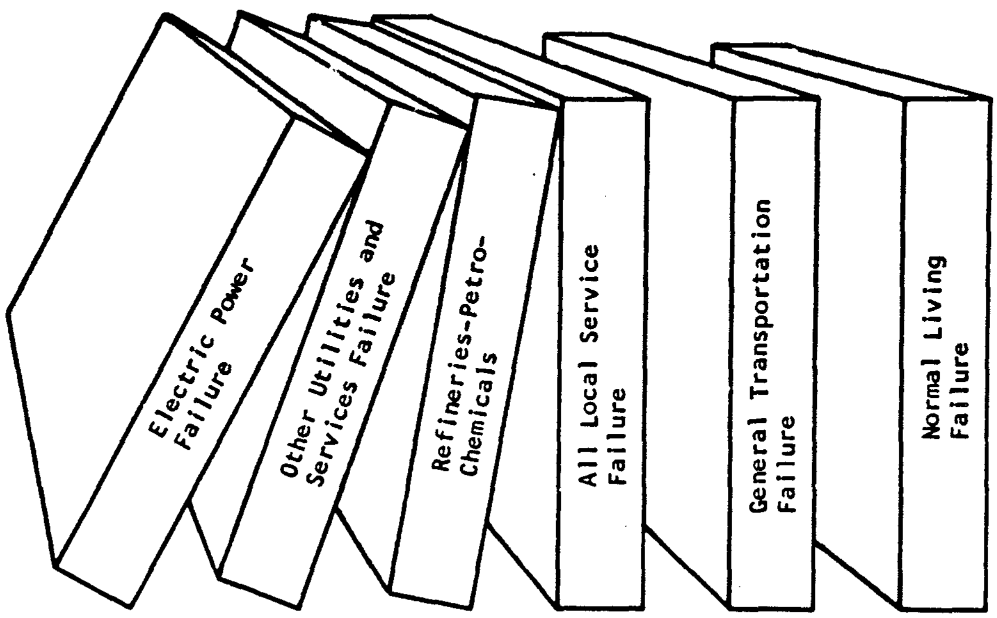


Figure 22. The Domino Effect

It is important that interdependence does not increase vulnerability and shut down frequency. A degree of self sufficiency becomes increasingly more important.

In a 1961 National Petroleum Council survey, a total of 67 refineries, representing 58% of the refining capacity of the country, were found to purchase 70.8% of their power from utilities. Also, 29.9% of the power was either self-supplied or was from a nearby generating plant. This information is shown in Table 13. Note in Region 2, less than 10% of the power is self-supplied. It is estimated that newer installations are more dependent on purchased power than the older ones.

Fortunately, in the "black out" of November 9, 1965, no refinery was seriously damaged. Of the three involved, only one had to shut down; the other two had enough auxiliary steam equipment (or were not cut off of their local source of power) to continue operation. The loss of output by a refinery during a shutdown is always substantial. The report points out that most refineries older than ten years are equipped with enough steam auxiliary equipment for continuous operation at reduced through-put or for an orderly and a normal shutdown. Where plants are completely dependent on outside sources of power, they could be damaged or have high losses by instant shutdown.

The nation wide industrial trend toward being completely dependent on outside power offers some matter of concern to defense planners. The National Petroleum Council report makes the following statement.[24] *"Recognizing the general dependency of the petroleum industry on purchased electric power, it is the suggestion of the committee that those planning to construct new facilities or expand existing facilities, examine the economics and operational feasibility of auxiliary generating and pumping facilities. In such instances, the expertise and views of the electric power industry would undoubtedly be available and prove most helpful."*

On June 5, 1967, another major power outage occurred. New Jersey, Delaware, the east half of Pennsylvania and a northeastern part of Maryland were affected. W.C. Huffman reports the effect on a refinery operation and what can happen, even in peace time.[25] Power was shut off for about four hours on much of the equipment of a 170,000 barrels a day crude capacity complete refinery. Power was furnished by a utility which supplies five substations in the refinery with power from four generating stations. "Within the plant, the newer units are wired so that each pump of a pair is powered from a different cable from the refinery substation, so that a power failure of a main cable is unlikely to cause such plants to shut down", so Huffman states; yet a complete outage did occur. See Figure 24.

In the plant discussed by Mr. Huffman, diesel-driven pumps supply 8500 GPM of river water at 120 psig for firefighting when needed. Steam-driven pumps were available at most services, but a partial failure in the steam plant caused considerable problem during this specific incident when two waste gas boilers went out of service because of automatic shutdown devices.

A fluid catalytic cracking unit, operating at a fresh-feed rate of 50,000 barrels per day and a combined-feed rate of 80,000 barrels per stream day, had a steam-turbine emergency cooling water pump capable of supplying about one-third of the normal circulating rate. This was enough water to prevent damage. Emergency power for lights and instrumentation was of great service during the rapid shutdown of the unit. Mr. Huffman concludes, "Although the damage to the refinery was not great relatively to what could have happened, it sharpened our concern with better preparation for emergencies." The cost of the 3½ hour power failure was estimated to be in excess of $250,000. Much of this loss was related to lost production.

The problems related to power failure will vary in degree of damage from plant to plant, yet all refineries either have or are destined to experience such a problem sometime during its operating history. The cost of one major outage could purchase, where it is needed, standby equipment which would at least soften the sudden blow of a complete power failure. *The point is made that the more self-sufficient a plant can be made, the better chance the plant has of riding out an emergency with minimum resultant damage and with a minimum of lost operation time.* In defense planning, it is imperative that each plant arrange for sufficient flexibility to meet probable emergencies created by both in-plant, natural, and created disasters. There is much to be done in this endeavor.

Emergency Preparedness - In case of a national emergency or in the case of some local power problem, some industrial links may be broken; each refinery could be forced to be on its own for a time until power lines could be repaired and until supply and product flow could be re-established. The rate of recovery will depend on location, advanced planning, and flexibility of operations.

"Today," as pointed out by the Defense Electric Power Administration, "fewer than 200 cities and towns of over 50,000 population contain about 60% of the population and associated industrial capacity of the nation. The larger generating facilities tend to be located near these population concentrations."[26]

"Generating capacity is the most difficult, costly, and time consuming component of an electric power system to replace and also tends to be highly concentrated geographically. If any portion of the power system is to be considered as a primary target, it would be these large generating systems." The dispersion of facilities is one of the best methods of industrial protection. This applies to all electric power as it does also to refining, petrochemicals, and closely allied operations.

The rhetorical question was asked by the DEPA, since it is well known that the size of generating plants is steadily increasing (possibly by a factor of 3 in the next 20 years), "Is the concentration of power generation making the industry more vulnerable to thermo-nuclear and other types of enemy action?"

Figure 25 shows the percentage of total power generating capacity supplied as of 1960 on one curve and projected to 1980 on another. Note that about 200 plants

---

24 National Petroleum Council - op.cit. page 8

25 Huffman, W. C. "Power Blackout Incidents and Plans Against Recurrence" American Petroleum Institute Division of Refining Meeting, May 15, 1968

26 Defense Electric Power Administration "Civil Defense Preparedness in the Electric Power Industry" U.S. Department of Interior- March 1966, page 13 A

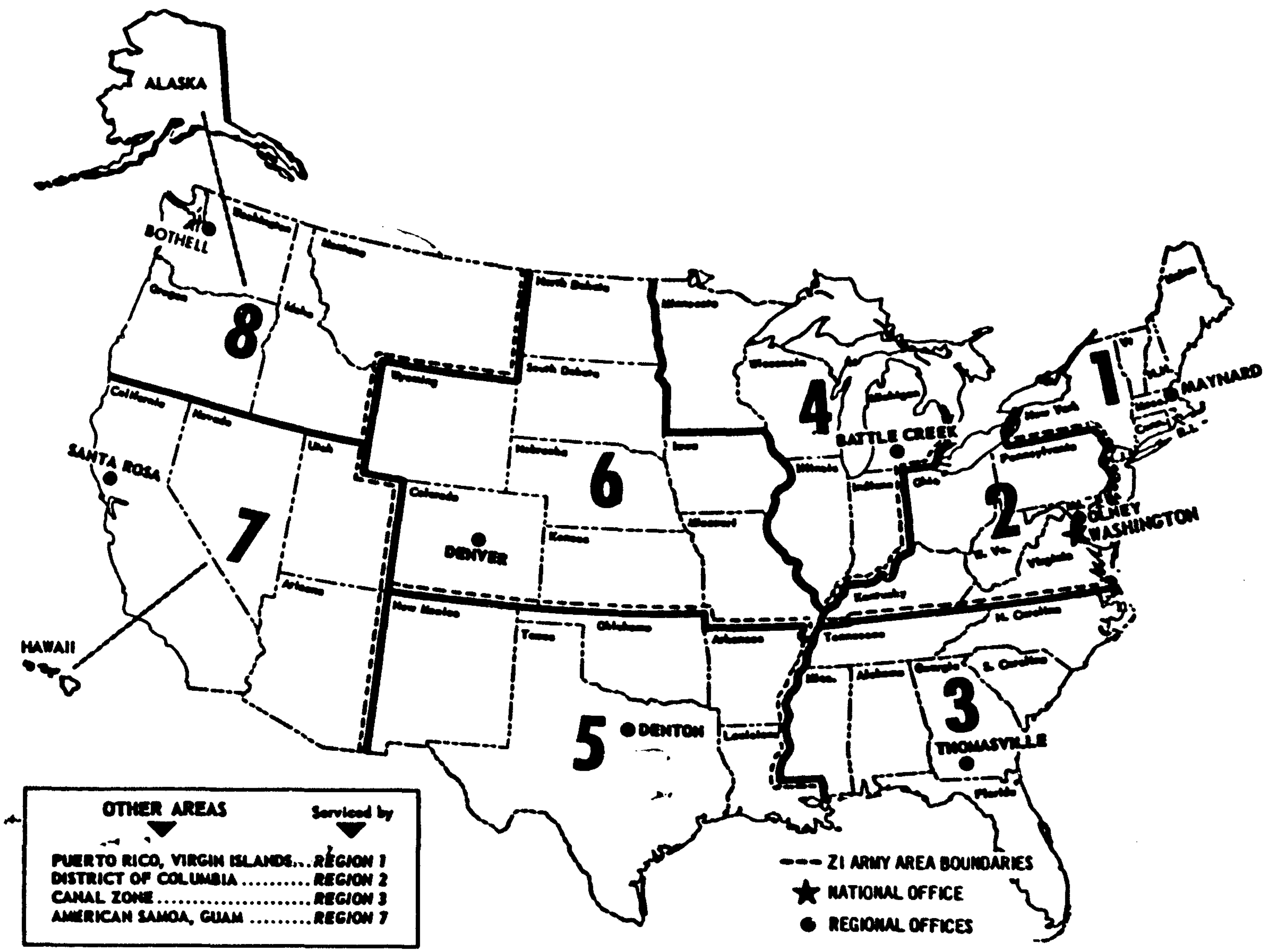


Figure 23. OEP–OCD* and Department of Interior Regions at the time of the Electric Power Requirement Study

*See Figure 93 for recent boundries

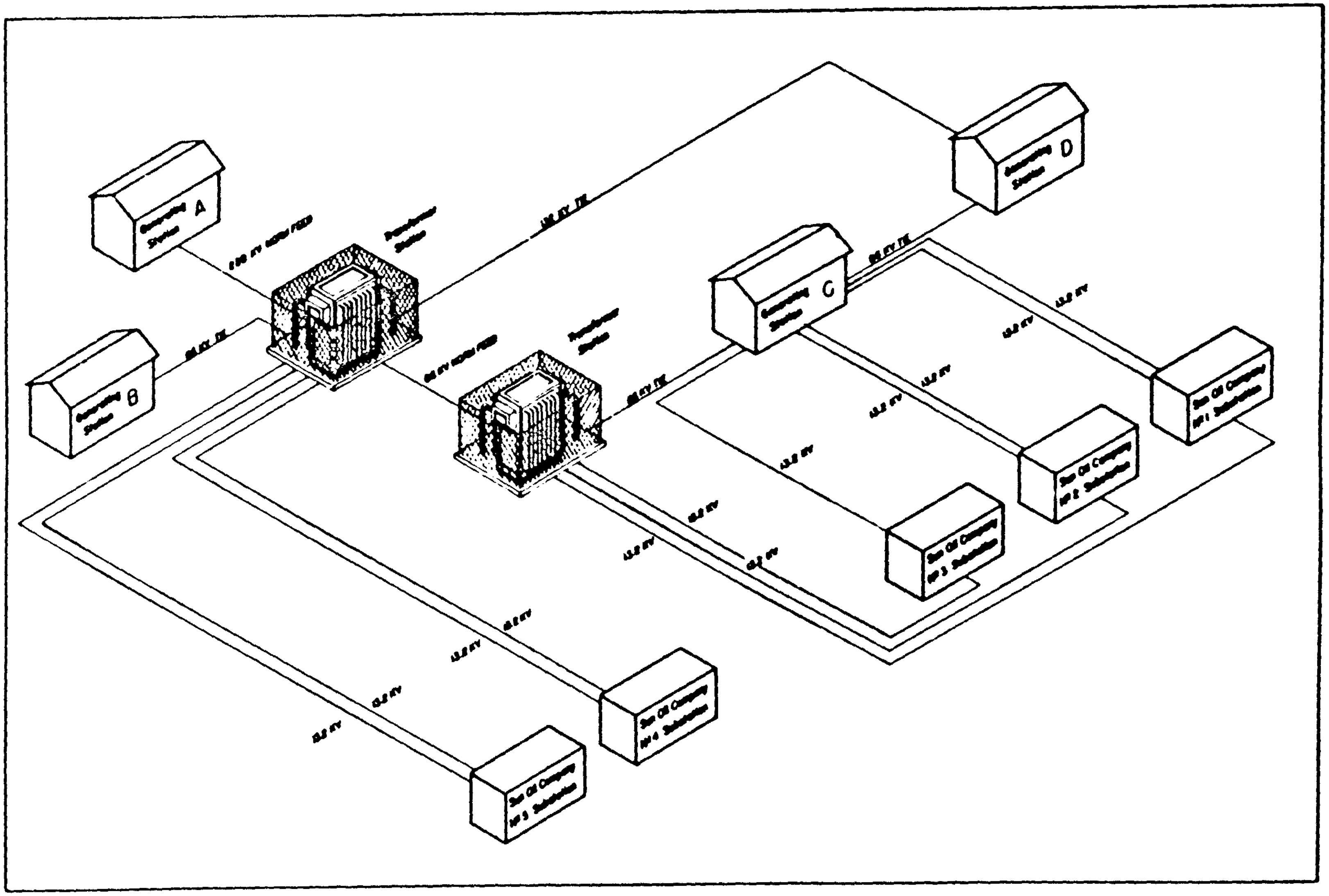


Figure 24. Electric Power Supply for a Modern Refinery (After W. C. Hoffman- cited above)

Table 13. Electric Power Requirements at Petroleum Refineries as of 1961 (Including New Construction By July 1, 1963)

Region(s)[1] OEP-OCD Region(s)[1]	Petroleum Refining Capacity Located in Area[2] (Bbls. S/D)	Percent of Refining Capacity Represented in Survey[3]	Electric Power Requirements (Figures Stated are in Kilowatt Hours Per Day)				
			Purchased From Utilities	Percent of Total	Self-Supplied	Percent of Total	Total Requirements
1	729,450	69.7	1,176,000	60.6	764,000	39.4	1,940,000
2	1,478,657	67.4	3,967,932	90.9	396,092	9.1	4,364,024
4	1,382,589	45.0	1,555,000	47.4	1,727,000	52.6	3,282,000
3 & 5	4,060,395	69.6	9,451,515	66.2	4,832,367	33.8	14,283,882
7	1,493,152	58.1	3,612,948	89.2	438,000	10.8	4,050,948
TOTAL							
United States	10,010,073[4]	58.2	19,763,395	70.8	8,157,459	29.2	27,920,854

[1] No refineries from Regions 6 and 8 included in NPC survey.

[2] Crude oil charge capacity as of January 1, 1961 – Bureau of Mines.

[3] National Petroleum Council survey for 1963 report – Chemical Manufacturing Facilities of the Petroleum and Natural Gas Industries.

[4] Includes refining capacities of Region 6 (607,830 b/d) and Region 8 (258,000 b/d).

From Impact of Electric Power Outages on Petroleum Industry Facilities – NPC – 1966

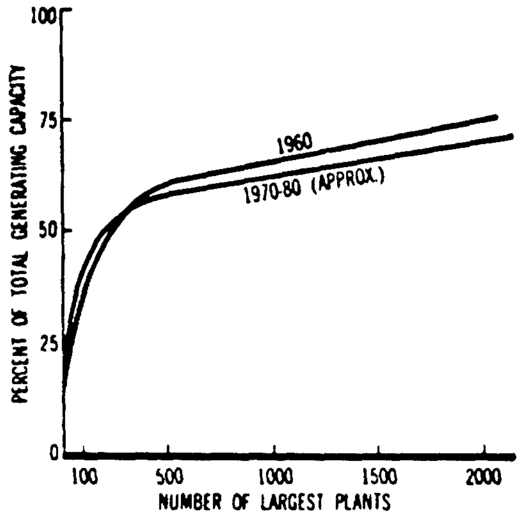


Figure 25. Percent of Total Capacity Supplied—by any given number of largest plants 1980.

From: Civil Defense Preparedness in the Electric Power Industry United States Department of the Interior- DEPA- March 1966.

generate 50 percent of our power, and also that the current building trend is toward reducing slightly the great dependency on a small number of large generating systems. Too much of the power source helping to generate of much of our gross national product is concentrated in too small an area for defense purposes.

In war, there is always the probability that an enemy bomb destroying a nearby generator will also destroy major parts of a nearby refinery, thus shutting it down completely also but this is not necessarily so. As refinery structures are strengthened, this danger will lessen. It seems evident that emergency and industry planners need to consider all possible causes of loss of power.

One cannot deny that power lines, substations, and power plants are easy enemy targets, and important ones. Bombing is not necessary to destroy them. A heavy chain properly placed can cause vast damage. Localized damage by line cutting, substation mutilation, and other methods of power interruption either by natural hazards or by sabotage, is an immediate problem of refinery management. Any move toward emergency self-sufficiency offers a refinery flexibility of operation not generally enjoyed under most existing conditions. Further, the protection of all major electrical circuits serving industry is of paramount importance to national security and of more than considerable interest to refinery management as well as to power companies.

Many methods of protection are well known. The use of underground installations, reinforced concrete tubes and tunnels, buried and encased cables, while more expensive than surf a installations, in a long view could prove to be the least costly. Any security added to installations including all factors of security fencing, guards, trained animals, and mechanical devices are usually considered by industry in the same view as "insurance".

It is outside the purview of this discussion to deal with retail distribution of gasoline and diesel fuels at the local filling station. But it might be suggested that retail dealers and wholesale terminals supply themselves with auxiliary power generators of a size adequate to meet their needs during a power outage. At least this would reduce much of the confusion created by this abnormal situation. A portable gasoline-driven generator, like those commonly used on an oil drilling rig, can generate enough power to run an average "filling station" keeping trucks and cars moving; this is vital to our way of living. Where auxiliary power is available, be certain there are several trained in its use and how to connect it to your present system.

The near complete dependence on electric power is only one part of the over-all problem. It is used only as an example of the effects of the loss of one link as demonstrated by experience and giving emphasis to the cost of such experience. There is a close tie between many industries in any normally operated society. The question arises as to what happens when normality is interrupted. What preparation has your plant made to meet the contingencies when these commercial bonds are broken?

Interdependency on Supply and Transportation

The amount and variety of spare parts carried in the refinery warehouse is gradually diminishing. The availability of these parts in nearby stores, the amount of tied-up capital, taxes, and the problems of protective storage combine to create this trend. Supply stores, in turn, for similar reasons carry a limited inventory and tend to depend on manufacturers hoping that rapid transportation can make delivery in time to satisfactorily serve the needs of a customer. The manufacturer, in turn, has limited warehouse facilities and often does not have a major part. He needs lead time in order to make it, after he once receives the order. An important building, one of the largest in the world, was deprived of heat for over a week when a large valve broke on a steam line at its heating plant. This is despite the fact that the manufacturer and supplier was located less than 100 miles away and all avenues of transportation and communication were open. No estimate of the monetary loss due to this failure of a simple part is available. If the item ordered happens to be in stock, then there is complete dependence on transportation, but this normally is no problem.

Electric Motors - The more specialized a system becomes, the more difficult it is to secure replacement items on short notice. But, how about commonly used items? The supply

of electric motors is only one example of a current situation. After having lost 153 electric motors in one evening when a storm caused a 3-phase line to single phase, the confusion created is still a hideous memory to an oil lease operator. Most motors can be protected for most conditions; short cuts are sure in time to cause problems. A 3-phase motor should be protected by three (not two) overload relays as well as fusetron type fuses rated not to exceed 25% of the name plate amperage. A magentic trip circuit breaker can be substituted for the "fusetrons." Lightning arrestors also are needed for added protection. In spite of such precautions, motors can be damaged by power supply problems and line breakage.

It is interesting to examine the current availability and delivery time of totally enclosed NEMA B and explosion-proof motors as used in refineries, natural gas plants and petrochemical manufacturing. Four leading suppliers were contacted to determine how many and where various size motors can now be obtained.

The inventory in Table 14 is not complete, for some local jobbers in a heavily industrialized area often carry some stock of motors commonly used by their customers. No complete record is available on these. Some of certain speeds and horsepowers will be available locally, but often only factory inventory is the sole source of supply of those motors of larger horsepower. Any urgent need for an electric motor of a certain size and speed could be met with disappointment and a long down time. Many sizes are "special order" with the delivery time extending from eight to twenty weeks depending on the size and type. Defense

Table 14. Availability of Electric Motors April 1969
3 Phase Explosion Proof and Totally Enclosed NEMA B

		Company 1		Company 2		Company 3		Company 4				
		Norwood, O.		St. Louis		Buffalo		Schenectady		Houston		Tulsa
	RPM	Ex.P.-	TEFC	Ex.P.-	TEFC	Ex.P.-	TEFC	Ex.P.-	TEFC.	Ex.P.-	TEFC	Ex.P.
25 hp	1200	0	5	0	3	2	2	0	10	0	0	
	1800	15	36	5	5	5	5	7	38 (18) (2)*	0	1	
	3600	3	5	4	6	3	2	3	7	1	1	
50 hp	1200	0	3	0	4	2	2	0	5	2	0	1
	1800	5	15	3	4	5	5	4	2 (18) (2)*	2	1	
	3600	0	3	0	5	3	3	0	4	1	1	
60 hp	1200	0	0	0	5	0	0	0	4	0	0	
	1800	0	0	0	4	4	4	3	14 (7)*	1	1	1
	3600	0	0	0	4	2	2	2	8	1	1	
75 hp	1200	0	5	0	4	0	0	0	4	0	0	
	1800	0	7	0	4	4	4	3	18 (4)*	1	1	1
	3600	0	2	0	0	2	2	2	3	1	0	
100 hp	1200	Special Order		0	2	0	0	0	4	0	0	
	1800	0	7	0	2	5	3	0	9 (4)*	1	1	
	3600	0	5	0	0	6	4	2	3	1	1	
125 hp	1200	0	0	0	1	0	0	0**	0	0	0	
	1800	0	5	0	2	2	3	0	5	0	0	
	3600	0	0	0	0	0	0	0	0**	0**	0**	
150 hp	1200	0	0	0	0	0	0	Special Order		Special Order		
	1800	20 wks. delivery		0	0	0	2	Delivery Variable		Del. Variable		
	3600	"	"	14 wks. deliv.		2	2	"	"	"	"	
200 hp	1200	"	"	"	"	0	0	"	"	"	"	
	1800	"	"	"	"	2	4	"	"	"	"	
	3600	"	"	"	"	3	5	"	"	"	"	
250 hp	1200	"	"	"	"	0	0	"	"	"	"	
	1800	"	"	"	"	0	0	"	"	"	"	
	3600	"	"	"	"	1	1	"	"	"	"	
300 hp	1200	"	"	"	"	Spec. Order		"	"	"	"	
	1800	"	"	"	"	"	"	"	"	"	"	
	3600	"	"	"	"	"	"	"	"	"	"	

* Different designs
** Not stocked

planners need to consider this problem. *Plant management needs to evaluate the risk of losing certain electrical equipment without spares available as a back up.* The re-winding of motors usually takes at least 24 to 48 hours. Here again, even the problems of bearing supply for larger motors and copper wire of the proper size have been known to cause substantial delays.

In time of a national emergency, repair parts could be even harder to acquire.

Electronic Equipment - As refinery operations become more computerized, requiring specially designed circuitry and instrumentation, it is expected that damage to a control panel or relay section could result in serious delays in operation, basically because of the time required to obtain replacement from various manufacturers. Down time and loss of product usually cost more than actual repairs. Risk could be reduced by having adequate standby equipment.

A control house is to a refinery what a head is to a human. It is possibly the most sensitive and most delicate of all areas of a refining operation. *The more delicate an operation, the higher the risk.* It not only is important that no one but trusted employees be allowed in or near the computerized area, but also that each one handling circuit boards be completely competent and his security be above question. Each employee must be alert. Serious damage can be readily created in a plant by a carelessly placed painter's ladder, a scrubwoman's mop or bucket, or loose tools in a hip pocket if such are turned loose in and around electronic and computer circuits. A bottle of coke spilled into a computerized system or even on a circuit board can raise havoc. Some plants have experienced accidents from the above mentioned causes. The time required for repair could be staggering.

The constructors of computerized installations well understand their frailties and their very sensitive nature. Often employees do not fully comprehend the extent of their hypersensitivity. For example, in some installations a very short break in the circuit operating the computerized system where information has been stored up for use, could cause the computer to temporarily lose its memory. One might be four hours into a computer cycle and have a frequency change or a short power break; if this computer is tied into several other computers, such a minor power change could require as much as twelve weeks to find a common point as a starting point to revitalize the system. Break-free systems are usually installed at computerized installations to prevent power interruption. In cases when the main power supply is interrupted for an extended time, there is a real need for turbine or diesel operated power to automatically come into play to replace the prime power sources.

While industry is interdependent one on another, so are workers dependent on each other to be ever alert to present "problems" which could endanger life, security operations, and the safety of others, or do damage to the industry furnishing them a living.

Major interruptions have occurred in operations during normal times for one reason or another. During the arranging and planning to meet the contingencies, a margin of safety can be added by stock piling extra parts, providing alternate supplies, standby power, extra pumps and compressors, and extra training of employees. Planning of this kind will make a refinery more self-sufficient and better prepared when either a local or national emergency arises.

Chemicals - In peace time, a short supply of chemicals to a refinery is mostly related to transportation delays. The number of sources are diversified enough to give considerable flexibility of supply. In time of war and transportation interruptions, some processes could want for sufficient treating chemicals. Defense operations would need to include the storage or stock piling of a reasonable amount of chemicals to cover a plant's demands for at least ninety days, or whatever practical amount could be kept on hand. Sulphuric acid for the alkylation process could be a special problem.

The fuels used in high performance gasoline engines need blending with tetraethyl lead $(C_2H_5)_4Pb$ and tetramethyl lead $(CH_3)_4Pb$. Straight run gasoline can be improved from 60 to 79± octane by the addition of 3 cc of tetraethyl lead if the sulphur content is less than 0.1%. Aviation gasoline, however, needs to have the iso-octane from the alkylation process added to straight run gasoline plus isopentane, butane and some aromatics such as toluene. A maximum of 4.6 cc per gallon of tetraethyl lead can be used to improve the octane rating of a aviation gasoline. The need for an alkylate is essential to produce most aviation fuels. This situation makes the tetraethyl lead producing plants and the alkylation plants of major importance.

Peace time supply of tetraethyl lead in the western hemisphere is normally no serious problem. The fact that only three processes are used to make TEL at present time and that only six plants furnish the domestic supply plus one in Canada makes the supply of material subject to easy interruption and the plants making TEL a target of high priority. Three plants are located in Texas, one in California, one in Ontario, and one each in New Jersey, Louisiana. Those defense regions with refining capacity would certainly need a nearby source of TEL in time of disaster. A recent trend to manufacture "lead free" gasoline may relieve this dependency in the distant future.

The supply of liquefiable petroleum gases (LPG), i.e. propane, propylene and butane used in the blending of gasoline, appears to be no problem to defense planners. Over 840 natural gas processing plants in at least 23 states not only produce the LPGs needed by the refinery, but also produce considerable natural gasoline to add to the market as needed. There is widespread use of LPG carburetors in farm machinery, trucks, and even passenger cars. Oil field machinery commonly runs on bottled gas (LPG). The natural gas processing industry is closely allied to the refining industry as to materials requirements as well as in its contribution to the national supply of liquid fuels. See Figures 26 and 27.

Critical Materials for Petroleum Refining Industry - At the request of the Department of the Interior, a study was made by the National Petroleum Council of the critical materials requirements of the petroleum refining industry[27] in time of emergency. While the thrust of this effort was directed toward conditions arising out of a nuclear action

27 National Petroleum Council "Critical Materials Requirements for Petroleum Refining" Washington, D. C. March 1966

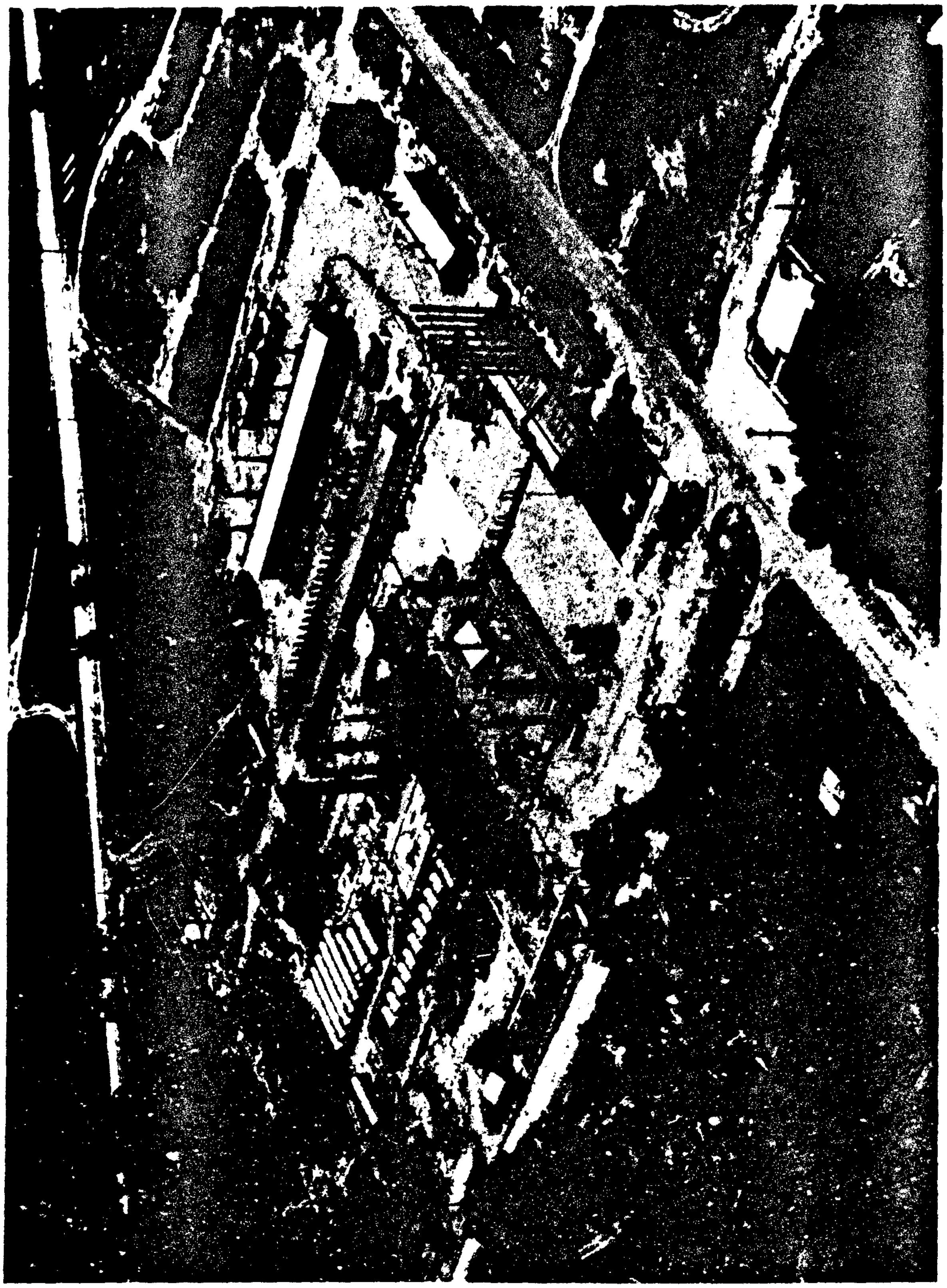


Figure 26. A Modern Natural Gas Processing Plant from the Air

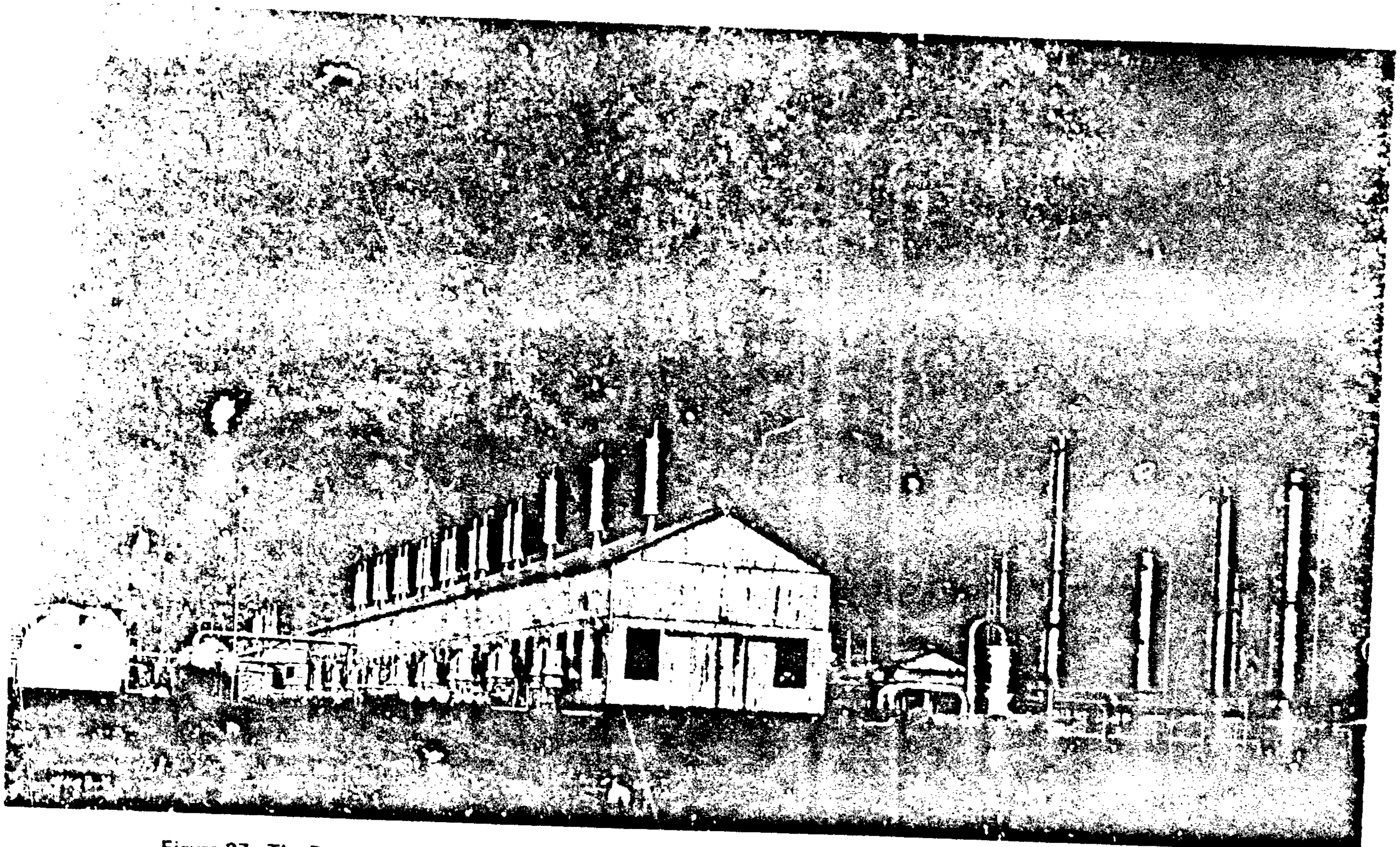


Figure 27. The Processing of Natural Gas to Make Liquefiable Gases and to Remove Liquids from Natural Gas.

and will be discussed further in later chapters - still the results of the study are fundamental and offer guidance toward a realization of the amount of each item required. Also other industries could be competing for the same material. A previously made study, National Petroleum Council, Report on Maintenance and Chemical Requirements of U.S. Petroleum Refineries and Natural Gasoline Plants, [28] is directed to this same problem. The tables 15 through 24 give an inventory of the average equipment required to build various refinery units. (See Appendix).

Even a small crude distillation plant of 10,000 B/SD could use up the nation's entire supply of explosion proof electric motors in one quick need. See Table 14. No complete study was made of the availability of electrical insulators except from experience to know that these seem to always be in short supply and often difficult to get on short notice. As for transformers, these appear to be even scarcer than explosion proof electric motors.

Several sizeable electric power utilities were questioned as to their policy on warehousing equipment. It appears that most utilities plan for ice storms, hurricanes, tornadoes, and a breakdown from normal usage. Those contacted had from six to eight months' supply of transformers, wire, poles and insulators on hand for growth and for local emergencies.

Planning for any emergency needs to take into consideration not only what likely will be destroyed in a disaster, but also how much of a disaster might be created in a plant by not having a spare piece of critical equipment which might be damaged in normal usage. Any planning for industrial preparedness and plant emergencies is useful effort and contributes generally to the plan for national defense.

No attempt is made here to consider the availability of suitable labor, it being assumed that no matter where a group chose to locate, an extensive training program would have to be conducted to train even experienced personnel in the handling of a new installation. Availability of labor and attitude of personnel toward work are important considerations to plant emergency and normal preparedness.

Dependency of Other Industries on the Petroleum Industry

It has been said by many economists and students of history that the strength of a nation can be determined by using its use of energy as an index. The petroleum and natural gas industry supplies most of this energy. While the refiner is dependent on the electric power industry, manufacturing, transportation and others, so also many people and industries are dependent on the refining industry to keep them supplied with their source of energy and basic raw materials.

Energy requirements in the future are discussed by Winger as follows: The Chase Manhattan Bank studies based on a probable population growth of forty-eight million people from 1965 to 1980, indicate that the energy requirements will continue to rocket upward. [29]

"In 1950, the annual per capita utilization of energy was equal to 39 barrels of oil. It is increased by the equivalent of 3 barrels within the next five years. But in the following five years, when the nation was feeling the fullest after effects of the declining birth rate many years earlier, per capita use rose by only 1.4 barrels. The third five-year period, however, witnessed a marked change in the opposite direction. By this time, the influence of the declining birth rate had waned and the effects of the accelerating rate that followed began to dominate. Between 1960 and 1965, per capita energy use climbed up by the equivalent of 5.4 barrels of oil- much more than in either of the two preceding five-year periods. And our studies indicate continued strong growth. Between 1965 and 1980, per capita energy use is expected to rise from 49 to 69 barrels equivalent- a gain twice as large as the growth in the 1950-65 period. The details are shown in Figure 28.

"Expressed in oil equivalent,* the nation's energy requirements in 1950 amounted to 16 million barrels per day. Growing at an average annual rate of 3.2 percent, they reached a level of 26 million barrels a day by 1965. A faster growth rate per annum after 1965 is expected to raise consumption to 46 million a day by 1980- almost three times as much as was needed only thirty years earlier, as shown in Figure 29. The accumulated consumption in the 1950-65 period totaled 113 billion equivalent barrels. And, in the 1965-80 period, it is expected to amount to 194 billion- almost three-fourths more than was used in the preceding fifteen years. Truly, the nation's needs in the near future are staggering." See Figure 30.

Oil is the leading source of energy accounting for 40+ percent of the nationwide market; natural gas is next- supplying 30+ percent of the over-all energy supply.

The report also commented on nuclear power. "Although nuclear power will soon become a major source of energy, it is still in its infancy and the amount currently utilized is insignificant compared with the other primary sources."

It is evident therefore, that any emergency affecting the free flow of petroleum and its related products can seriously affect the welfare of a nation.

Petrochemicals - The relationship existing between the refining and natural gasoline industry with the petrochemical industry is such a close one that some refiners scarcely know which industry they are in. Usually they are in both. A modern refinery may supply ammonia for farmers; acetylene for welders; carbon black for tires and newspapers; ethylene for solvents, plastics, and refrigerants; propylene for explosives, solvents and detergents; butadiene for nylon; toluene for explosives, and asphalt for roofing and roads. All are primary products of a modern refinery. Tables 25, 26 and 27 show the close association and dependence of other industries to refining. Petroleum refining is a vital,

28 National Petroleum Council "Report on Maintenance and Chemical Requirements for U. S. Petroleum Refineries and Natural Gasoline Plants" Washington, D. C. 1961

29 Winger, John G., Emerson, John D., and Gunning, Gerald D. "Outlook for Energy in the United States" The Chase Manhattan Bank, N. A. New York, October 1968

*See Supplement for Btu relationships between fuels

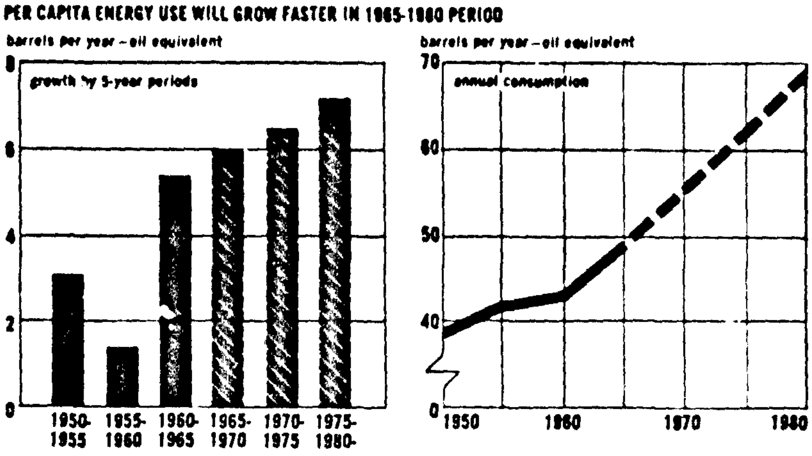


Figure 28.

Source: "Outlook for Energy in the United States," The Chase Manhattan Bank, N.A. - October 1968.

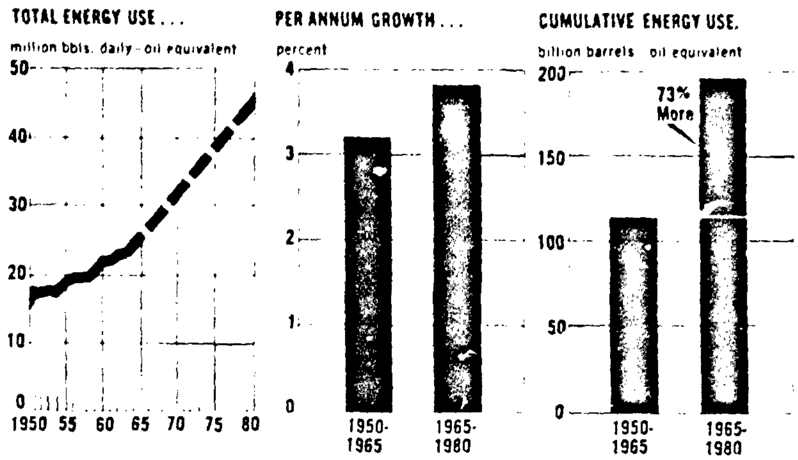


Figure 29.

Source: "Outlook for Energy in the United States," The Chase Manhattan Bank, N.A. - October 1968.

basic, and critical industry having great responsibilities to many dependent chemical manufacturing plants. For one example, four-fifths of the feed stock to organic chemical plants are petroleum products.

In the past, hundreds of "coal tar" products were made from the distillation of coal. Now, essentially all "coal tar" products can be and are made from petroleum products, and all except the "squeak" from the pumping unit in the "oil patch" is used. The petroleum industry is now a source of food and clothing, besides energy and chemicals. A report from the Wall Street Journal as reprinted by the National Academy of Sciences [30] discusses the broad responsibility of the oil and gas industries.

30 Reproduced from National Academy of Sciences "Role of Petrochemical Industry in Recovery from Nuclear Attack and Recommended Plans to Reduce Vulnerability" Advisory Committee on Emergency Planning, December 1961

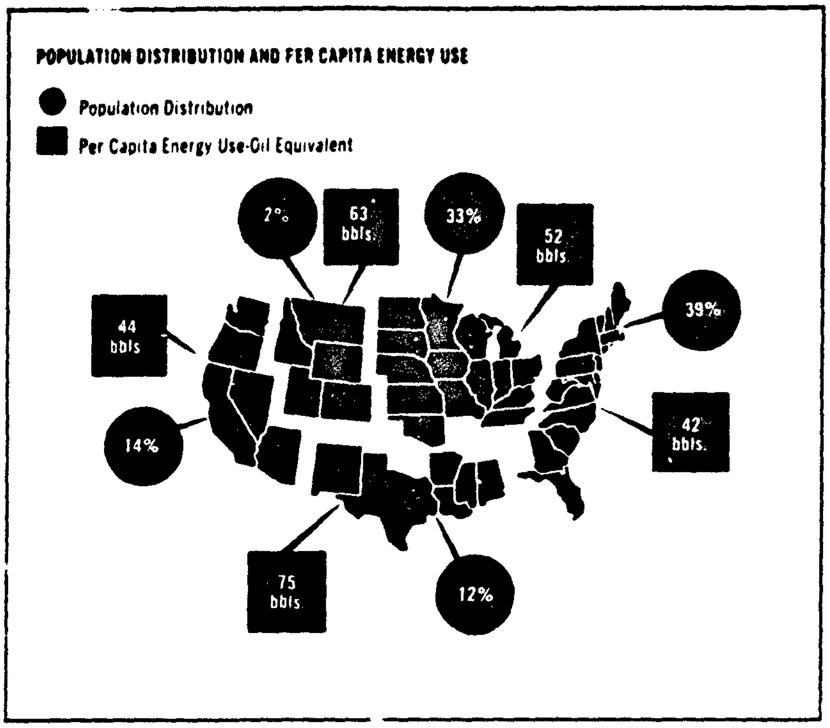


Figure 30. Population Distribution and Per Capita Energy Use

Source: "Outlook for Energy in the United States," The Chase Manhattan Bank, N.A. - October 1968 (See supplemental tables - Energy Balance and U.S. Consumption of Primary Energy.

"The world's vast supplies of oil and natural gas soon may provide a major source of food for the hungry populations of underdeveloped lands. Scientists in a Pittsburgh laboratory of Gulf Oil Corp. already are turning petroleum into cookies, soups and cerials. At an undisclosed United States location, a pilot plant of Standard Oil Co. of New Jersey and Switzerland's Nestle Alimentana, S.A., is refining oil into an almost tasteless white powder that could serve as a protein-rich dietary supplement for people and animals. Elsewhere in the U.S. and Europe, edible vitamin and protein concentrates, synthetic meats, and other foods are being produced experimentally from oil and natural gas. Animals already are on a 'petroleum diet' in several countries. In a Russian research project, cattle and poultry are being fattened on some 1,000 tons a year of foodstuffs processed from petroleum. Pigs on an experimental stock farm in Nigeria are being raised on similar rations." At present British Petroleum at Laverne, France has the only commercial size plant. Its products are used in animal feed.

An executive from a large oil company recently stated that the protein requirement for the entire world can presently be made from one percent of the crude daily processed in the refineries in the United States. Food from petroleum is discussed in detail in a recent series of articles in Hydrocarbon Processing.[31]

It is possible in time of a prolonged war that life itself will be dependent on the petroleum industry to furnish food concentrates. Radioactive farm land, exposed products, transportation failure, and the loss of farm help could affect the usual food supply.

Protection Problems

Civil Defense Industrial Preparedness is concerned: one, that existing operations be protected as much as possible from all dangers created either by nature or by people; and two, that new plants be located and designed to give utmost consideration to safety and strength and to the protection of equipment and employees. Plants should be built to meet the international environment in which we now live.

31 Pryor, Takata, Bennett, Decarle, et al "Food from Petroleum" Hydrocarbon Processing, March 1969, pages 95 - 112

Energy Balance -- Initial Appraisal
(In Trillions of BTU's)

The following table summarizes the National Petroleum Council's initial appraisal of the U.S. Energy Outlook through 1985. Supply-demand relationships are projected assuming that (1) current government policies and regulations and (2) present economic climate for the energy industries would continue without major changes throughout the 1971-1985 period.

		1970	1975	1980	1985
U.S. Domestic Energy Consumption*		67,827	83,481	102,581	124,942
Projected Domestic Supply:†					
Oil – Conventional‡		21,048§	22,789	24,323	23,405
Synthetic		--	--	--	197
	Subtotal	21,048	22,789	24,323	23,602
Gas – Conventional‡		22,388§	20,430	18,030	14,960
Synthetic		--	380	570	940
	Subtotal	22,388	20,810	18,600	15,900
Coal		13,062	16,310	19,928	23,150
Hydropower		2,677	2,840	3,033	3,118
Nuclear		240	3,340	9,490	21,500
Geothermal		7	120	343	514
TOTAL DOMESTIC SUPPLY		59,422	66,209	75,717	87,784
(Percent of U.S. Consumption)		87.6	79.3	73.8	70.3
Imports Required to Balance:					
Oil		7,455	15,662	22,984	30,878
(Percent of Oil Supply)		22.0	40.7	48.6	56.6
Gas		950	1,610	3,880	6,280
(Percent of Gas Supply)		4.1	7.2	17.3	28.3
TOTAL IMPORTS		8,405	17,272	26,864	37,158
(Percent of Energy Supply)		12.4	20.7	26.2	29.7

* As projected by the Energy Demand Task Group.
† As projected by the various Fuel Task Groups; oil and coal adjusted to meet demands as predicted by the Energy Demand Task Group.
‡ Includes Alaska North Slope Starting in 1975 for oil and 1977 for gas.
§ Excludes additions to oil (2,086) and gas (132) stocks.
Excludes BTU's consumed in conversion of coal to syngas.

Source: National Petroleum Council, *U.S. Energy Outlook--An Initial Appraisal (1971-1985).*

U.S. Consumption of Primary Commercial Energy

	Thousands of Barrels Daily of Oil Equivalent			
	1955	1960	1965	1970
Nuclear Energy		3	18	97
Hydropower	707	836	968	1,296
Coal	5,528	4,906	5,838	6,707
Natural Gas	4,361	5,982	7,622	10,206
Oil	8,278	9,453	10,963	14,094
Total	18,874	21,180	25,409	32,400

	Percent of Total Primary Commercial Energy Consumption			
	1955	1960	1965	1970
Nuclear Energy		*	0.1	0.3
Hydropower	3.7	4.0	3.8	4.0
Coal	29.3	23.2	22.9	20.7
Natural Gas	23.1	28.2	30.0	31.5
Oil	43.9	44.6	43.2	43.5
Total	100.0	100.0	100.0	100.0

Source: *Office of Oil and Gas*
U.S. Department of the Interior
July 28, 1970

NOTE: 1970 estimated

Considering the constant tension of world affairs, no wise builder should build in the center of a prime target area without applying the vast reservoir of plans and knowledge prepared by the Office of Civil Defense. From the standpoint of national security, no industrial building should be erected in congested areas.

Virgil Couch, Director of the Industrial Participation, Office of Civil Defense,[32] points out, "Production everywhere depends on production somewhere else. Wreck one plant and production is stopped in another plant far away. There is no place to hide anything or anybody from all the effects of an attack. But we can protect our most priceless asset, people, and our ability to recover, by making plans in advance for industrial survival . . . . No plant is immune to catastrophe. Emergency action plans, therefore, should be ready to meet all evantualities- both peace time and wartime hazards . . . .

"Sabotage is an effective means of attack. Therefore, industry should take appropriate measures to prevent the commission by misguided persons or enemy agents of any destructive act to endanger employees or impair the productive capacity of the plant . . . ."

Production problems are often strongly affected by industrial concentration and congestion. Mr. Couch continues,

"Obviously, the best defense method for protecting our domestic mobilization base and ensuring survival is industrial dispersion. Where deconcentration aims at scattering the manufacture of a particular item, dispersal of industry is directed at thinning out industrial areas so as to minimize the destruction of industrial capacity by attack on a given target. This is the employment of the simple military measure of using space and topography for defense of industrial plants against attack. Consideration should be given also to placing the entire plant underground.

"By multiplying the number of targets an enemy must hit to inflict the same total damage, industrial dispersal tends to reduce the total effects of attack on our capability to produce.

"As industrial plants are established in less concentrated areas, and employees and their families move to these locations, metropolitan-area populations are thinned to some extent, making those areas less attractive as enemy targets. In addition to dispersal of production, it is evident that certain finished items, especially materials necessary for survival, be dispersed and available for immediate use following attack.

"The Federal Government particularly urges the dispersion of new and expanding industrial facilities."

In another statement, Couch says, "The basic philosophy on which civil defense is based is 'self help' in time of emergency. Every individual, industrial plant, city and state must

32 Couch, Virgil L. "How To Prepare for Civil Defense in Industry" Industrial Security, July 1962, page 8

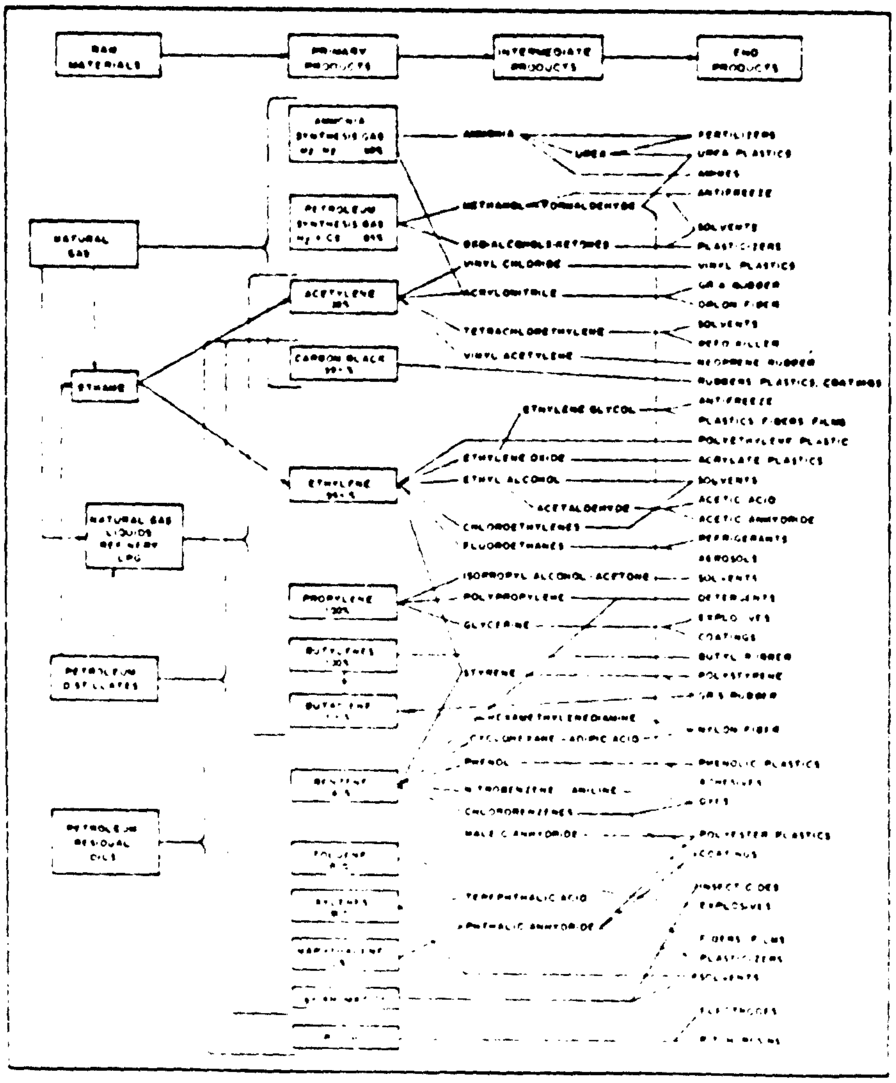


Table 25. Chemicals and End Products Derived fromPetroleum and Gas

Source: "Role of Petrochemical Industry In Recovery from Nuclear Attack and Recommended Plans to Reduce Vulnerability." National Academy of Sciences- December 1967.

be prepared and capable of meeting disaster. This is a 'do-it-yourself' job in the true sense of the word." 33

Pasma, 34 at the time Chief, Industrial Dispersion Division, U.S. Department of Commerce, makes this statement.

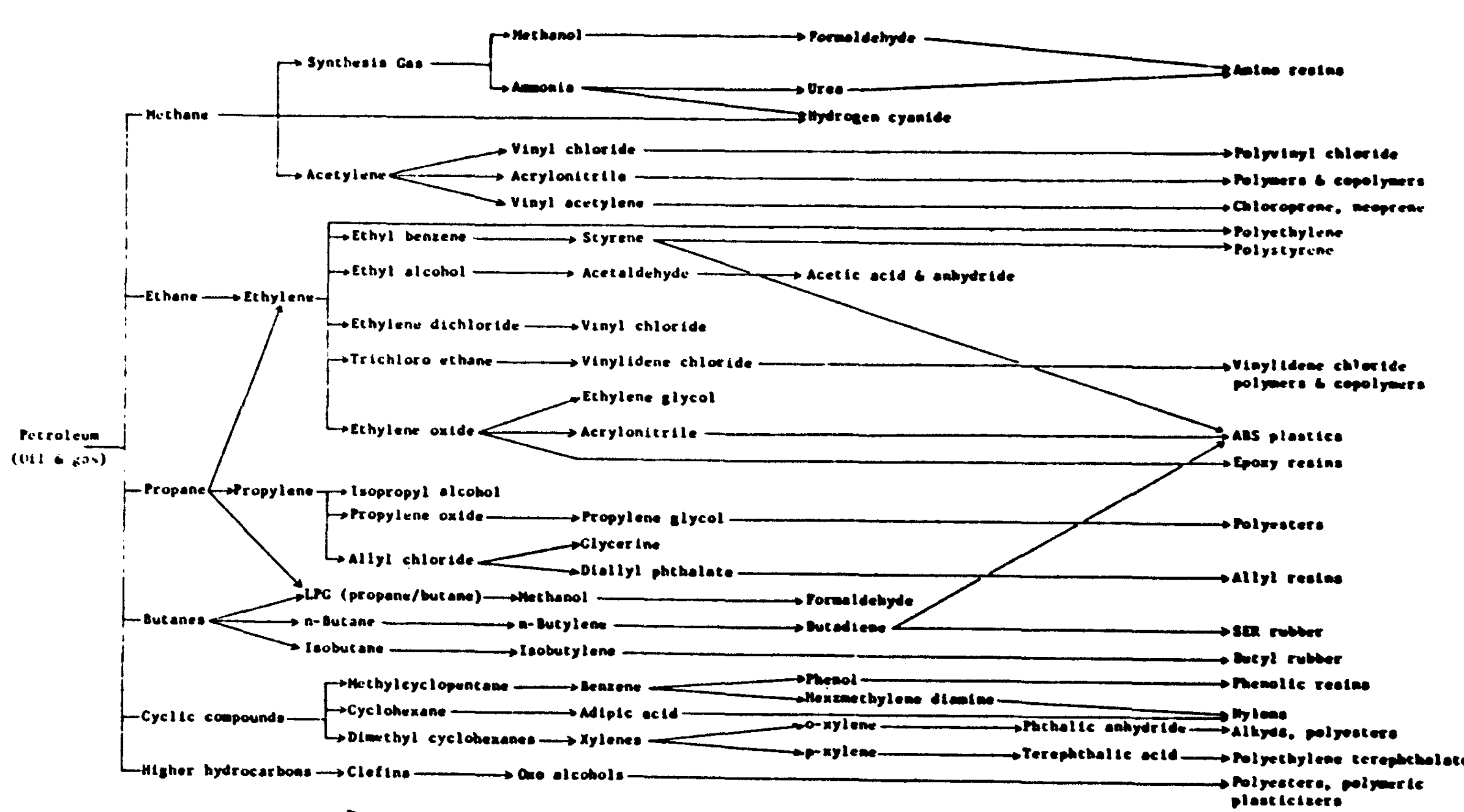
"The serious impact of our manufacturing plant vulnerability to potential aerial attack is brought out when we consider the fact that 70 percent of our defense-supporting productive capacity and 54 percent of our industrial workers are contained in 50 of our major metropolitan areas. The threat to these cities- and the industrial plants located there- is the great dismaying condition which surrounds all that we plan, all that we do.

"Statements on weapon effects recently made by the Chairman of the Atomic Energy Commission make it clear

34 Pasma, T. K. "Assessment of Plant Vulnerability" U. S. Department of Commerce, Article in Civil Defender, Industrial Issue, page 15

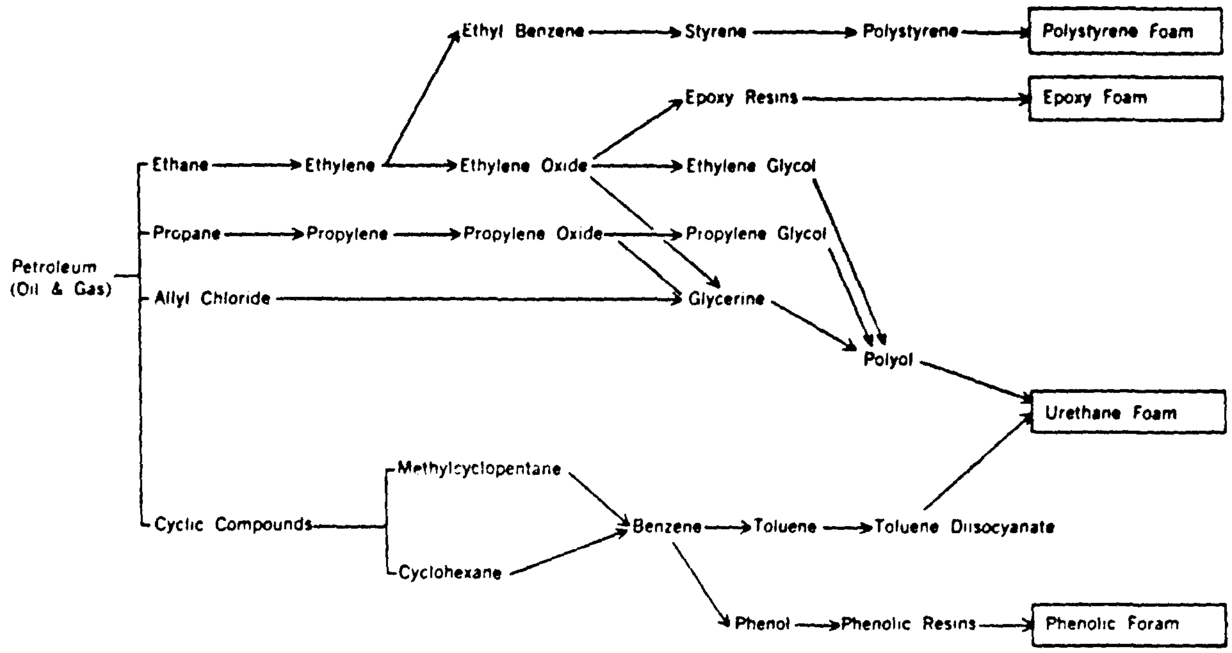
33 Couch, Virgil L. "The National Program for Industrial Survival" Civil Defender, Industrial Issue, page 12

Table 26. Plastics From Petroleum



Data from A.P. Lien, Battelle Memorial Institute, "Plastics as Constructive Materials for Developing Countries," United Nation's Inter-Regional Conference on the Development of Petrochemical Industries in Developing Countries, Teheran, October 1964.

Table 27. Foam Plastics Derived From Petroleum



Source: "Structural Potential of Foam Plastics for Housing in Underdeveloped Areas", Research Report on ORA Project 05687, Architectural Research Laboratory, University of Michigan, Ann Arbor.

that it is still possible to reduce by dispersal the disastrous effects of blast and heat when accompanied by protective measures against weapons of mass destruction, because an enemy deprived of profitable targets is actually deprived of striking power.

"To accomplish dispersion by space, the present nationwide dispersion policy calls upon Federal agencies to encourage and when appropriate, to require that new facilities and major expansions of existing facilities important to national security be located so as to reduce the incorporation of suitable protective construction features in such facilities to provide resistance to weapons effects.

"Since industrial facilities now being built will be used for decades wherever located, planning for their locations must be projected decades ahead."

Keeler,[35] formerly the Vice President of the Chase Manhattan Bank in charge of security, discussed the concentration of industry and of population.

"There is a close correlation between manufacturing areas and areas of dense metropolitan and county population.

"Our productive resources tend to be concentrated in densely populated regions, and since our industries will be prime targets, this makes us vulnerable. For example:

a. East of the Mississippi and north of the Ohio Rivers is an area containing 88 percent of our iron and steel production, 96 percent of our electrical equipment manufacturing plants, and 31 percent of the 50 most populous cities.

b. More than half of the total population of the country lives in 70 critical target areas which include half of the industrial production but only 3 percent of the total area of the country. These are civilian target areas and do not include military targets, such as bomber bases and atomic energy installations.

c. An attack on 10 of our most strategically-situated cities would encompass one-third of our industrial workers and establishments, and reduce our transportation system to but a fraction of its normal capacity.

"Upon examination of this industrial-economic data and the areas involved which are highly vulnerable not only to missiles and aircraft, but also to sabotage, one can immediately grasp their significance, not only to our economy, but to the war-carrying potential of the U.S. These areas are the backbone of production for items essential to conducting a war and to survival."

35 Keeler, Frank J. "Determining Vulnerability of Your Plant to Attack" Industrial Security, July 1962, page 24

Stocker,[36] at the time of the article, Associate Editor of the American Machinist, McGraw-Hill, summarized a vital current problem as follows:

"How do you start to analyze facilities vulnerability? Here are some questions which, when answered in terms of your situation, may provide a foundation for building your program. Start now! When disaster strikes, you can only wish you had."

"1. Is any one critical item produced exclusively in the plant or target area? Do you know of a remote second source? How long would it take to duplicate production?

"2. Have you surveyed the possibility of decentralizing this production to other areas of the plant, or to other geographic locations? Can you gain by relocating for distribution or labor source as a direct benefit of decentralization?

"3. Have you considered transferring some of your employees with special knowledge and skill to other locations or other areas of the plant to minimize loss of production know-how resulting from having them all in one area? Are you training people to fill skilled-labor, technical, and management positions? How many alternates are available right now? How many 'cadres' could you organize to expand or rebuild your manufacturing force?

"4. Are you using protective construction to reduce the danger to personnel and key facilities? Are personnel trained in shut-down procedures if danger threatens?

"5. Have you considered alternate locations for storage of raw materials, tools, and inactive machinery? Have you arranged for storage, away from the plant, of complete drawings and instructions for repair and rebuilding of ciritical facilities?

"6. Have alternate suppliers been determined? Alternate transportation facilities? What power sources are available? How vulnerable is your present power system? Can it be improved?

"7. Has the feasibility of a revision of specifications and standards been considered, where such action enables additional plants to participate in manufacturing essential items? Have you studied facilities of neighboring plants to determine which of your critical items they could produce in an emergency?

"8. Have your suppliers been analyzed to determine the danger of delivery failures resulting from vulnerability or dangerous concentration?

"9. Are your hazardous departments, stores, or operations separated from the remainder of the plant. Have you considered drop curtains or draught breaks in large open areas? Can you isolate trouble at any place where it may start?

"10. Do you have a working stock, and an emergency list, of critical replacement parts for machines and equipment? Would they be likely to suffer simultaneously with the equipment they replace?

"11. Have method engineers, design engineers, production and tool engineers, and all supervisory help been instructed in the problem of vulnerability and the means of minimizing it? Is there conscious effort to avoid critical conditions?

"12. Is your program planned to operate under disaster conditions if necessary? Or, is it based on normal day-to-day operations? Remember that conveniences such as power, light, telephone, water, and transportation may be lacking after disaster strikes."

Soon both the east coast from Maine to Florida and the west coast from San Francisco to Mexico will be giant megalopolis-like cities. They will be "sitting ducks" to submarine as well as being within missile range. Protection from natural operational hazards created by hurricanes and earthquakes offer some encouragement to management to deploy inland but market considerations, transportation and crude supply still outweigh these factors. Much needs to be done in serious study of new plant location. Perhaps newly developed waterways will aid in some solution of this problem. The January Bulletin, 1962, of the Atomic Scientist summarized the situation as follows: "As to dispersal of population and industry (which could afford a certain measure of protection against all kinds of attack), we as yet have almost none of it. Instead, new skyscrapers are going up in the most congested areas; and some basic industries have continued their concentrations in metropolitan centers already replete with major targets."

---

36 Stocker, Wm. M. "Deconcentration of Production" Civil Defender, Industrial Issue, page 36

Chapter V

RISK SUSCEPTABILITY DUE TO THE NATURE OF THE PRODUCT AND EQUIPMENT

The Situation

"BLAST, FIRE HIT REFINERY AT PORT ARTHUR, 3 INJURED"- "REFINERY BLAST LEAVES 2 DEAD"- "CHARRED DESTRUCTION MARKS SCENE OF TANK CAR BLASTS"- "BLAST INJURES SEVERAL"- EXPLOSION KILLS A MAN"- are a few of the headlines which appeared in a local paper within a short period of time. Considering the fact that refineries manufacture liquid fuels and sensitive chemicals, it is a tribute to the industry that major explosions are not commonplace. However, we need to do even better in industry and correct the present trend.

Couch,[37] speaking before the American Society for Industrial Security, said, "Today as a typical day in terms of disasters, we could expect to have more than 360 fires alone in industrial plants in this country. A majority of those fires would cost in excess of twenty thousand dollars and one would exceed a cost of a quarter of a million dollars. And about once every ten days there is a fire which costs over a million dollars, typical of the kind of disasters that we're concerned with. If today is a typical day in terms of disasters we could expect thirty-three companies to suffer some kind of damage through natural disaster. Now I don't mean nickel-and-dime window breaking or flood or this kind of thing, but an expensive costly loss from disaster, plus the fact that we have numerous highway hazards, transportation hazards, railroad hazards, and by the transit of flammable materials and toxic materials which could create disaster. At almost every industrial seminar of this type, ASIS seminars that I have attended in the past twelve years, some three, four or five people in attendance get calls to return home because of a disaster. Because they've had a major fire, there's been an explosion, there's been a flood, there's been a tornado, there's been something that has caused people to be called to go back home. These are typical of the kinds of things that we are talking about here today."

"The main thing is, as we look at this, are you prepared? Are you ready to deal with this kind of disaster? It's well recognized also that if you are prepared to deal with a natural disaster, unquestionably you are better prepared to deal with a disaster that might be caused by enemy attack. In time of war, we're faced not only with the possibility of the loss of our people, loss of our plants, but loss of our country. Yes, the entire loss of our country."

The use of higher pressures and with hydrogen and hydrocarbon mixtures along with plant congestion, long pipe lines, large vessels, and high velocity vapor lines, losses trend to become increasing in magnitude with each accident in oil refineries and petrochemical plants. The more complex the plant, the more difficult it is to repair and the greater the down time. The American Insurance Association discusses risk analysis in chemical manufacturing at great length. Certainly no refinery or petrochemical plant management should be without this bulletin of the American Insurance Company. (Technical Survey No. 3)-(See Reference 4).

In Table 3, taken from that publication, various causes of plant losses are listed. To repeat, Table 4 points out that of all 317 plant losses studied in a sample survey, over 60 percent of the major plant losses involved explosions and in 26.5 percent of the cases, both explosions and fires combined to cause extensive plant damage.

Spiegelman,[38] commenting further on the chemical and allied industries' large losses, states, *"Large losses are occurring with much greater frequency.* On examining a group of these accidents, it became apparent that such losses, including equipment failures and business interruptions averaged about $200,000 to $300,000 per failure. The increase in the size of plants and process units has had an adverse effect on the entire loss experience...." See Table 28.

Spiegelman continues, "In contrast to the fire and explosion record of the chemical and allied industries, the accident record, as reported by the National Safety Council for the years 1964 through 1966, is better than the all-industry average. However, the frequency and severity record of accidents in some parts of the chemical industry indicates a number of problem areas. This is particularly noticeable in those areas of the chemical industry involving explosives, salt processing, synthetic rubber and fertilizer products."

Charney,[39] Systems Manager for Fenwal, Inc., in addressing members of the American Institute of Chemical Engineers, said, "The present trend in the chemical industry toward large, automated, single-train plants has increased the likelihood of disastrous losses due to the fire and explosion hazard of massive spills of flammable hydrocarbons."

Although loss of life and injury is minimal in a refinery operation, still equipment losses and repair time appear to be generally increasing if not in frequency, certainly in cost. The protection of equipment and any improvement that can be made to safeguard against fires and explosions will pay handsome dividends and go a long way toward making the plant more durable in time of enemy attack.

---

37 Couch, Virgil L. Panel- "Professional Civil Defense Training Available to Industry" Proceedings American Society for Industrial Security- Philadelphia, Pennsylvania, page 117, September 22, 1966.

38 Spiegelman, Arthur "Risk Evaluation of Chemical Plants" 64th National Meeting American Institute of Chemical Engineers- New Orleans, La. March 1969, Paper 25 A, Also Footnote 4

39 Charney, Marvin "Flame Inhibition of Vapor - Air Mixture" American Institute of Chemical Engineers Meeting- New Orleans, La. March 1969- Paper 29 A.

Table 28. Chemical and Allied Industries Large Losses

(Excluding Boiler and Machinery and Business Interruption)

Year	No. of Fires and Explosions	Total Fatalities	Total Injured	Total Property Damage
1966	37	19	287	$27,220,000
1965	32	16	66	$29,976,000
1964	29	18	106	$21,386,000
1963	31	6	115	$32,379,000
1962	21	17	135	$16,296,000
1961	26	13	313	$12,978,000
1960	20	30	111	$25,532,000

Detonations

Texas City Disaster- An example of a disaster originating outside of the plant which destroyed petroleum facilities, occurred at Texas City, Texas. A small fire in the hold of the French ship, Grand Camp, moored in the Texas City harbor, set off two devastating explosions on April 16, 1947 The explosion and spreading fires killed 512 people, injured 1784 others, and destroyed property valued in excess of fifty million dollars. Refineries and oil storage terminals became active participants in short order. Greater spacing from the potential hazard might have helped. See Figure 31. The petroleum installations in this case were victims of their locations.

The 7716 gross ton vessel had been fighting a small fire of chemical fertilizer cargo in the hold for more than an hour before the initial explosion. The first explosion from below was immediately followed by a tremendous blast that wrecked large portions of the crowded industrial and residential sections of the area. Twenty-seven firemen were killed in the explosion.

The High Flyer, a vessel of 6214 tons, caught fire, and 15 hours later its cargo of ammonium nitrate exploded destroying with it the Wilson B. Keene (7716 gross tons). See Figure 32. Several hundred freight cars, much of the cargo stored at the Texas City Terminal Railway Company, and oil storage tanks were only a part of the material destroyed. A Horton sphere of a pipeline company was tilted off its base. It looked like a flying saucer after a forced landing. It looked good outside at casual glance, except for its stance but was crumbled on the inside. It was junked. Fires blazed everywhere, buildings collapsed, homes were blasted to the ground. A nuclear blast could scarcely have been more damaging.

Thirty or so organizations rallied to the call of Civil Defense, including the Navy, Army, National Guard, American Red Cross, Texas Department of Public Safety. Many worked diligently to save lives, get people to the two small hospitals of the city and set up emergency operations of traffic, fire fighting, rescue, clean-up, and restoration. See Figure 33.

Mutual Aid Plans- This explosion illustrated a need for industrial decongestion and for the development of disaster plans both in the community and with each company. Although a start was made a month earlier to organize a community disaster committee, the full need of such an effort was demonstrated before the committee could do little more than make a few plans. So often it takes a disaster to demonstrate a need.

As an outgrowth of the disaster, the Texas City Industrial Mutual Aid System was developed. The need for the organization did not have to be sold to those who had experienced devastation created by the harbor explosion. Gilmore of the Monsanto Chemical Company [40] discussed the Mutual Aid group in an Industrial Defense Symposium May 5th, 1965.

"A Mutual Aid organization has many factors that are necessary to a successful system. There must be a purpose which motivates the group. This may seem obvious, but it should be remembered that this type of organization brings together representatives of many business and governmental entities, men of different professions, different business interests, and even business competitors. Therefore, there must be a purpose, strong enough to command the cooperation of these representatives. Because the Mutual Aid purpose embraces the minimization of loss of life and property and asks men to help others who need their help, the organization does command the cooperation and respect of the members.

---

40 Gilmore, Charles "The Texas City Industrial Mutual Aid System" - An address before the Industrial Defense Symposium- May 5, 1965. The Provost Marshal's Hdq.- 4th U. S. Army, Fort Sam Houston, Texas. Reprinted by U. S. Office of Civil Defense.

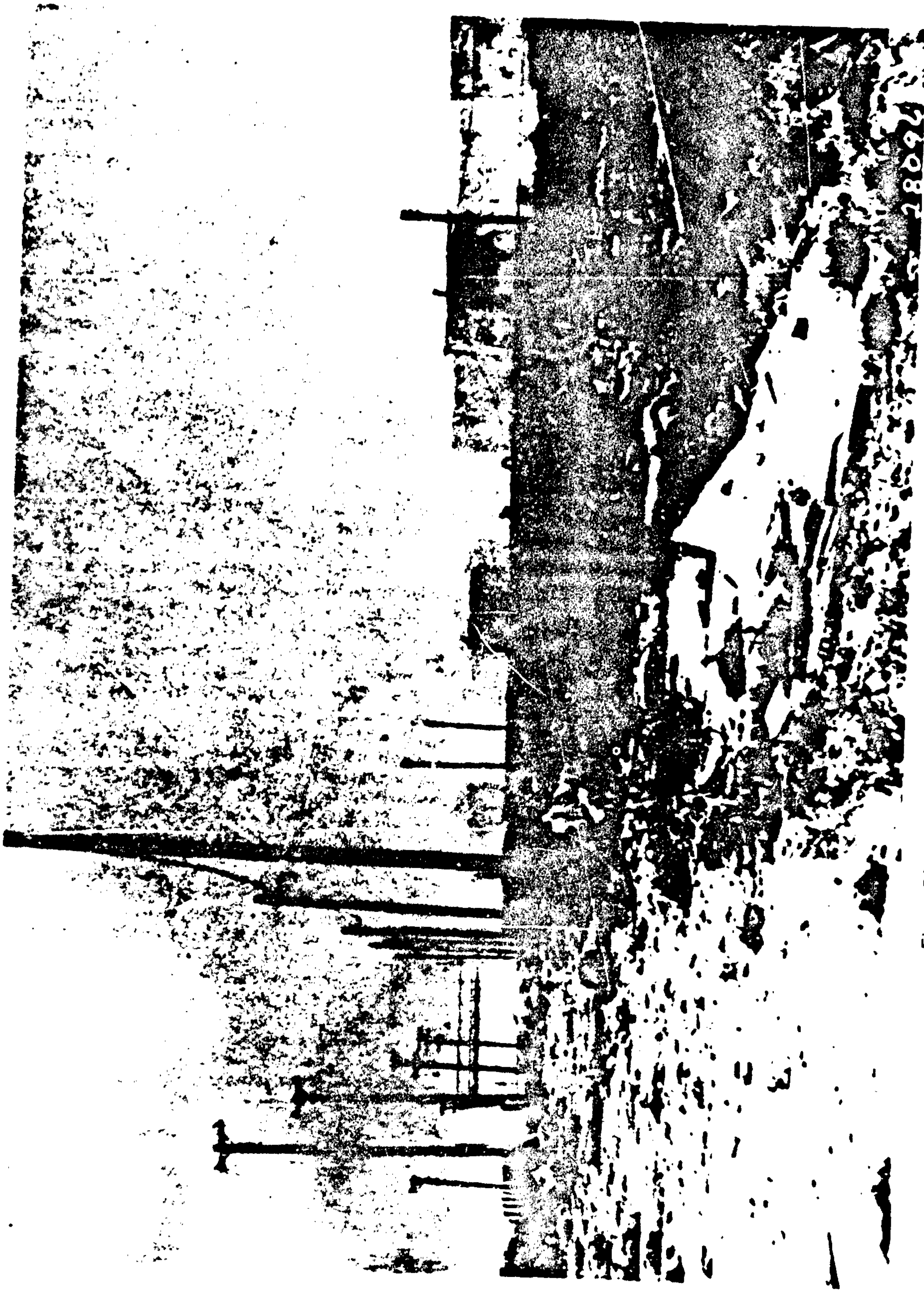


Figure 31. Refineries and Tank Farms Were Innocent Bystanders.

Figure 32. The Wilson B. Keene Was Seriously Damaged As Was the Entire Terminal Area.

Figure 33. Civil Defense, American Red Cross, The U.S. Navy, Army and National Guard, the Texas Department of Public Safety, Over Thirty Organizations Came to Help.

"Because of this purpose, these members must have a plan of action– because of the variety of the interests represented, the plan must be definite, written and understood. The plan must be inclusive, to cover all of the activities necessary to accomplish the purpose of mutual assistance.

"No system– No plan is worth anything when you need it unless it is a practical plan tested by drills. Most plans work on paper, but "The proof is in the eating"– I have never heard of a plan that worked without a hitch, oftentimes these failures occur even after testing, but this is true only because every real emergency is different, containing some item that wasn't planned. Without drills though, the failures will be more frequent, more costly, and more severe. No matter what your plan may be, test it – often enough to maintain interests, maintain effectiveness, and maintain competence of action."

In summary, he points out, "The supporting procedures are important in all member organizations – the industrial plants, the police and fire departments, the utilities, the medical, the news media – every member.

"I have talked about the factors that make or break a Mutual Aid Organization. There are undoubtedly other factors that some of you have experienced, but these are the basics –

Organized leadership
Cooperation between industry and government
A written and rehearsed plan
Communication – the key to success
Supply – availability lists understood
Medical assistance
Traffic control
Public information through news media and supporting procedures."

The Office of Civil defense has extensive files which include many emergency plans of companies and many mutual aid plans of communities. They have motion pictures available as to how to organize a mutual aid plan and how such should work. Help in organizing such plans can be obtained from the Office of Civil Defense, The Pentagon, Washington, D. C. 20310. It does not take a major disaster to reap benefit from a mutual aid plan. Its constant use by industry has paid off many times.

Whiting, Indiana- One example of an in-plant detonation was the catastrophe at Whiting. Management, engineers and operators of the American Oil Company refinery were awakened at 6:12 August 27, 1955 "by the sharpest sound I have ever heard," said Ducommun,[41] Vice President of Manufacturing, (deceased) American Oil Company, in discussing this detonation. A large fluid hydroformer was leveled by the blast. The detonation shattered a 5½-inch thick drum (8 times thicker than needed for operating pressures). Fragments from the reactor were scattered over a radius of 1200 feet. Some missiles invaded the tank area. "The impact on the tanks caused numerous fires which spread rapidly throughout the tank field ultimately bringing more than 40 acres within the fire area and eventually destroying sixty-three tanks and approximately 1,270,000 barrels of crude and various products," according to Jacobs, Bulkley, Rhodes and Speer.[42] One 60-ton piece landed in a tank containing gasoline-base stock. It was the same in weight as a DC-7 crashing on the spot, except this "aircraft" traveled only 1200 feet on its maiden flight. The first explosion occurred within the reactor vessel and high pressure separator. Other detonations took place in the piping, exchangers, a separator drum, absorber tower, and other pieces of equipment. See Figure 34.

Jacobs, et al. describe eye witness accounts. "At the time of the explosion, a number of people in the immediate vicinity of the refinery, (sufficiently close so that the transit time for sound would be well under 1 sec.) saw luminous flames issue from near the top of the hydroformer. After several seconds they heard a loud report from that direction, and then they saw the 'large' vessel (reactor) disintegrate and the pieces fly through the air. Subsequently, they heard a second more violent report and soon the area was enveloped in smoke and flames.

"Most of the operators on the unit were in the vicinity of the control room at the time. Generally, they recalled a rumbling noise, then a first explosion which knocked some of them down; this report was followed by a cloud of smoke and dust which greatly reduced visibility. After they had recovered their footing and had started to run, a second violent detonation occurred, again knocking some of them off their feet. After this, there was a number of small explosions."

One would believe this to be some account from a war-torn industrial area. And, there is complete similarity of problems.

"At the time of the explosion, the unit was being started up after a shutdown for mechanical repairs," Jacobs continues.

"At this stage of the start-up, the two major vessels, reactor and regenerator, were being heated simultaneously, the latter with compressed air through the air heater B-5 via the combustion air line, and the former by circulation of inert gas through the combination furnace B-1. The air system was normally held at about 10 lb./sq. in. lower pressure than the inert gas system. Naphtha circulation through the unit (except the reactor, which was bypassed for this operation) was in progress. Through a series of unfortunate circumstances, the recirculating inert gas became contaminated with air and naphtha vapors, forming a flammable mixture estimated to contain about 19% O_2 and 3% naphtha vapor at about 105 lb./sq. in gauge. No catalyst was present in the system at the time.

"The Fluid Hydroformer stood 260 ft. above ground level. The reactor vessel was 127 ft. in total length and 23.5 ft. in diameter. It was fabricated of alloy steel plates varying in thickness from 2-3/8 to 2-3/4 in. Two regenerator exhaust stacks and six relief valve outlets are shown at the top of the unit." (The wreckage at the unit site is shown in the frontispieces). "About 44% of the reactor vessel was

41 Ducommun, Jesse C. "6:12 at FHU-700" American Petroleum Institute Chicago, Illinois, November 14, 1956

42 Jacobs, P. B., Bulkley, W. L., Rhodes, J. C., and Speer, T. L. "Destruction of a Large Refinery Unit by Gaseous Detonation" Chemical Engin. Progress, December 1957, Vol. 53, No. 12, page 565

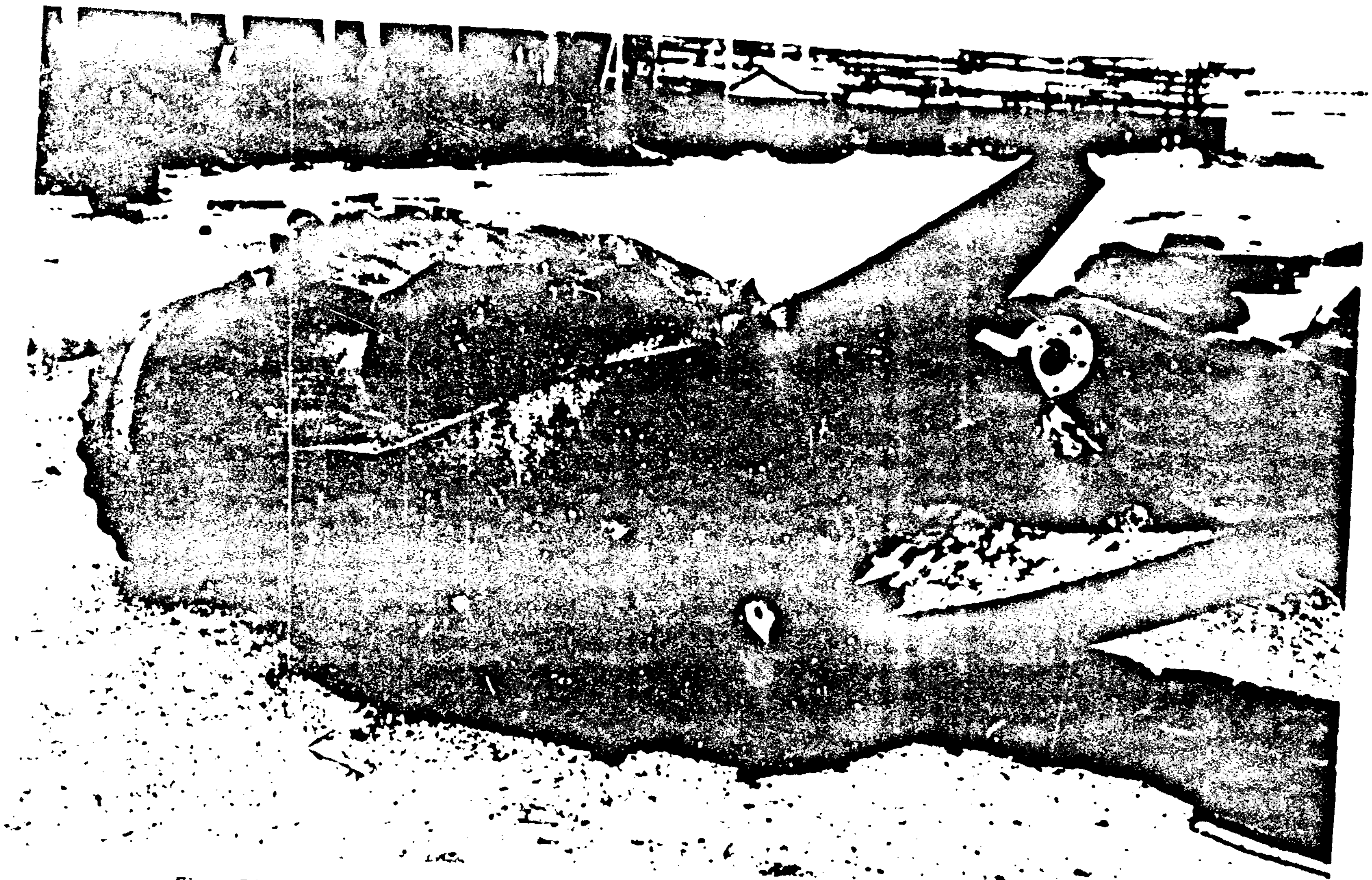


Figure 34. These Detonation Fragments From a 5½-inch Thick Drum (8 Times Thicker Than Needed for Operating Pressure) Illustrate That it is Impractical to Design for Detonative Forces. A Shell That Was 30 to 50 Times Thicker Than Needed Probably Would Not Have Resisted the Detonation! Shattered by a Detonation of Propane-Oxygen Mixture.

Source: American Oil Company Photo

hurled beyond the area shown; pieces remaining can be seen in the upper central portion of the photograph."

Only nine employees lost time as a direct result of the explosion. Eleven suffered injuries during the fire fighting. A 3-year old boy outside of the refinery was fatally injured, and his brother suffered an amputation. One man died of a heart attack.

Another interesting account is given by Ducommun.[41] "When we reached the battery limit of the hydroformer we found gasoline, light cat-cycle oil, and heavy cat-cycle oil from the two cracking units gushing out of the ground. The fountain flowed out of lines that were buried some 2-1/2 feet deep. A huge chunk of steel from the ruptured vessel had lighted on this area and severed 4-, 6-, and 8-inch lines as one would a slice of bread.

"Already some men had started a sand dike, diverting the oil flow into a nearby sewer. This was the start of another important activity of this day and many days to come: the building of secondary sand dikes to control the flow of oil." This turned out to be of extreme importance.

Ducommun continues, "No fire had started when these lines were severed but the roar and din in the area was tremendous. Part of the noise was from a big tank to the north of us. Four-hundred-pound and 100-pound steam lines, a 100-pound air line, and the gas lines – lines that had been severed at the battery limit – added to the high-pitched cacophany. The call quickly went out to shut off the main valves which could be seen in the distance.

"Then we were at the hydroformer itself. There was not too much fire but the shambles and destruction were almost indescribable.

"According to the consensus of eye witnesses, there was a loud thud or muffled explosion, followed by a sheet of flame which surrounded the reactor. Then there were two loud, sharp explosions. According to one witness, the reactor seemed to 'peel' apart. This observation was substantiated by the reverse curvature found on some of the fragments. Oil spills followed shortly in the tank fields.

"The 600-ton reactor shell broke into 13 major-sized pieces, ranging from 3 to 136 tons. Of these, a 60-ton fragment traveled farthest – 1,200 feet. The separator broke into 29 pieces, one of which was found 1,500 feet away. About 20 storage tanks were hit, a vapor recovery unit was struck, and the elevators on one of the fluid cat crackers were damaged. With the possible exception of one naphtha tank, no equipment would have been scrapped because of mechanical damage from fragments alone. Excepting the fluid hydroformer, the major damage in the refinery was due to the subsequent fire.

"It was humanly impossible to extinguish this conflagration," Ducommun continues. "Fire fighters who entered the tank fields to contain individual fires, were driven out by flash fires resulting from oil spills. The fire could only be controlled. A few minutes after the hydroformer exploded, the perimeter of the fire had enclosed most of the pressure stills, tank fields and the heavy tank field. The area covered scaled to about 17.5 acres.

"After two hours, the fire area had increased to around 20 acres. The overflowing of the tank field and spill into Indianapolis Boulevard increased the fire area to 42 acres by noon. This doubling of the area aflame, however, represented only an average lineal advance of the fire front of about 25 percent.

"After Saturday noon, the net fire area steadily shrank. Later ignitions or boilovers in the east, such as the one around 4:00 P.M. Sunday, increased the total burned area to about 47 acres. However, concurrent shrinkage on the west was more rapid so that the net acreage of fire actually decreased.

"Several hours after the fire started it was recognized that fire-fighting would continue through the night. An emergency fire-fighting organization was established to provide manpower on the customery three-shift basis at five different fire-fighting zones. This organization included the doctors and nurses at our refinery hospital. In the afternoon, some of the men were sent home to rest to enable them to return on a later shift and relieve those on duty. This arrangement provided more effective fire-fighting around the clock and continued for several days. Several thousand men were involved during the first days of the fire. This number decreased until there were about 50 men per shift assigned to active fire-fighting duty during the last few days.

"Our emergency plans, made and practiced through the years, certainly proved their value and confirmed the wisdom of having such plans and practices. Our up-to-date fire-fighting equipment and trained manpower proved they can handle a major emergency.

"Take a look at our fire-fighting brigade. A full force of about 300 refinery employees, fully trained in the newest techniques, is backed up by 300 more, partly trained, regular refinery personnel. A Chief heads a full-time staff of 11 fire marshals who work on shifts around the clock.

"The refinery is equipped to fight any fire. There are more than 400 hydrants in the high-pressure, looped water system; 11 stationary pumps maintain 175 pounds pressure whenever there is a siren call. Fifty-one turret nozzles are located at key spots. So many streams were played on this fire that pressure dropped to 70 pounds at the peak. However, there was never a shortage of water.

"Seven fire trucks, 44 hose carts, and nearly 80,000 feet of fire hose are stored throughout the plant, ready for use. More than 2,600 first aid extinguishers are strategically located.

"Fire-fighting is part of everyone's job at Whiting. That we teach and that we practiced when the major disaster alarm sounded. It was a signal for employees, wherever they might be, to report to the refinery for duty. They reported, they performed according to plan, they won.

"In addition to the curtain of water raised about the fire, the most effective control was applied by the construction of temporary sand dikes. About 2,500 loads of sand were hauled by the refinery and neighboring trucking companies to provide emergency dikes. This sand, plus an equal amount, was used to advantage after the fire to soak up the oil in the fire area and facilitate dismantling. Almost every trucking facility in the community was engaged in this huge task.

"Feeding men on duty during a fire was another major task. A mobile canteen of the Salvation Army voluntarily

entered the refinery within one to two hours after the explosion. Subsequently arrangements were made with a catering service that operated on a round-the-clock basis for two days to provide sandwiches, coffee, and milk on radio call from any area in the refinery.

"Civil Defense, National Guard, and 12 police agencies aided in patrol, communications, and in three different and successive evacuations of the residential areas. The Red Cross, American Legion, Whiting Community Center, and about 40 other agencies provided medical and other aid in the community....

"Bear in mind, this older area at Whiting was built in the early '90's. Some of these tanks were installed in the late '90's and early 1900's. When they were constructed they matched the highest safety and material specifications of their time, and we had kept these facilities as up to date as reasonably possible.

"Most facilities performed according to design. For example, our sewer system, designed back at the turn of the century, carried off much of the dangerous liquid and helped prevent a worse disaster.

"Materials used for fire-proofing structures paid handsome dividends. Concrete-covered, steel-pipe stanchions carrying vital lines withstood exposure to high temperatures and many lines of welded construction remained intact. Steel valves and steel pump casings resisted the searing heat while cast iron valves and cast iron fittings simply disintegrated. Threaded and screwed pipe couplings separated, leaving hundreds of disjointed lengths of curling pipe.

"We quickly learned that emergency communications are vital in a disaster such as this. Telephone cables providing service in a refinery were damaged by the explosion and other cables serving parts of the city were destroyed later by the fire. From the time of the first alarm practically all of the existing telephone service was disrupted. It was necessary to use radio-equipped cars and trucks for communication. The refinery had about 36 of them and some were set up at key locations throughout the plant to maintain communication."

Ponca City, Oklahoma- Pipkin [43] reminds us that problems of detonation are not confined to new processes alone. Old processes are not immune from troubles.

"Ole No. 1 Dubbs had made her last run, but this we didn't know until later." The experienced coke men had cleaned out the still as they had done so many times during the past 30 years that no one was sure how many. The operation crew of old timers took on the system and proceeded to start it up as they could easily do in their "sleep". These men were not trainees, but experienced operators. A vent valve was overlooked and was not opened during filling operation. Ram oil, a light gas oil, was used as a start-up charge. It was observed that the unit was filling slowly, but this was attributed to cold stock. When the filling pump began to run hot, still the clue to coming trouble was not grasped. The pressure was built to 90 psig when fluid movement stopped. The operators decided that a low fire in the furnace would help warm the cold oil. It was cold outside and the oil just might be thick. The vent was still closed.

"A fire at this stage was not normal, but also not an unusual thing to do. Now after several hours the flow rate was about 800 barrels per day, a low fire burned in the furnace, and no oil was overflowing into the dephlegmator.

"As the pressure approached 200 psig at the furnace inlet, the operators checked the pressure at the top of the coke chamber; it was 200 psig and climbing. Something was really wrong! Everything suddenly became clear and action became urgent. The vent was still closed. An attempt was made to open it, but it was now impossible by hand. A man went for a wrench; he never made it in time. At 6:00 A.M. January 22, 1959, No. 1 Dubbs dephlegmator ripped open with a violent explosion. The procedure of 'start-up' was the same as hundreds of times before- except for the closed vent valve. Old units are not immune to explosions." (Note: An airplane pilot uses a check list when he warms up his engine even though he has flown 1,000,000 miles). See Figure 35.

"The analysis of the cause of the explosion was judged to be spontaneous ignition- iron sulphide deposits could have contributed to the temperature and air in the system.

"A 100 pound sheet of steel boiler plate landed 300 feet away and crashed through a roof into a dining room. One man was killed; window glass was broken; the north and south ends of the control room windows caved in; one man trapped in the tool house by fire went to safety out the window in record time. A piece of the dephlegmator weighing 7440 pounds flew 100 feet; a 2500 pound fragment, including the top head, blew 335 feet into a residential area. Window damage occurred 5000 feet away. Projectile damage is sometimes a problem in such blasts."

Everyone knew the vent valve should be open. Seemingly harmless changes in procedure might be a fatal catastrophe. It is suggested that grating for platforms makes less destructive missiles than floor plates.

No refining system is free from potential hazards, a conclusion borne out by several hundred accounts of refinery damage reviewed for this presentation.

Analysis of Detonations and Explosions

It is not the purpose of this discussion to be a complete treatise on the anatomy of detonations or normal explosions, for this information is covered by hundreds of well-known papers. It is helpful, however, to review observations of those who have lived through and studied such accidents in detail as a guide to preventing accidents and as a guide as to what to expect. Such experience is training for Civil Defense problems that could occur in time of war since secondary explosions and fires will be commonplace in industrial centers in any bombing situation. A study of actual events that have occurred in our industry should better prepare us for problems related to all disasters; but instead of having only one plant involved, there may be several.

Most investigators of explosive processes recognize *two types of explosions:* (1) a normal type where it is possible to calculate the maximum pressure generated in the destruc-

43 Pipkin, O. A. "Detonation- Old Processes are not Immune" American Petroleum Institute, Chicago, Illinois Meeting, November 1959

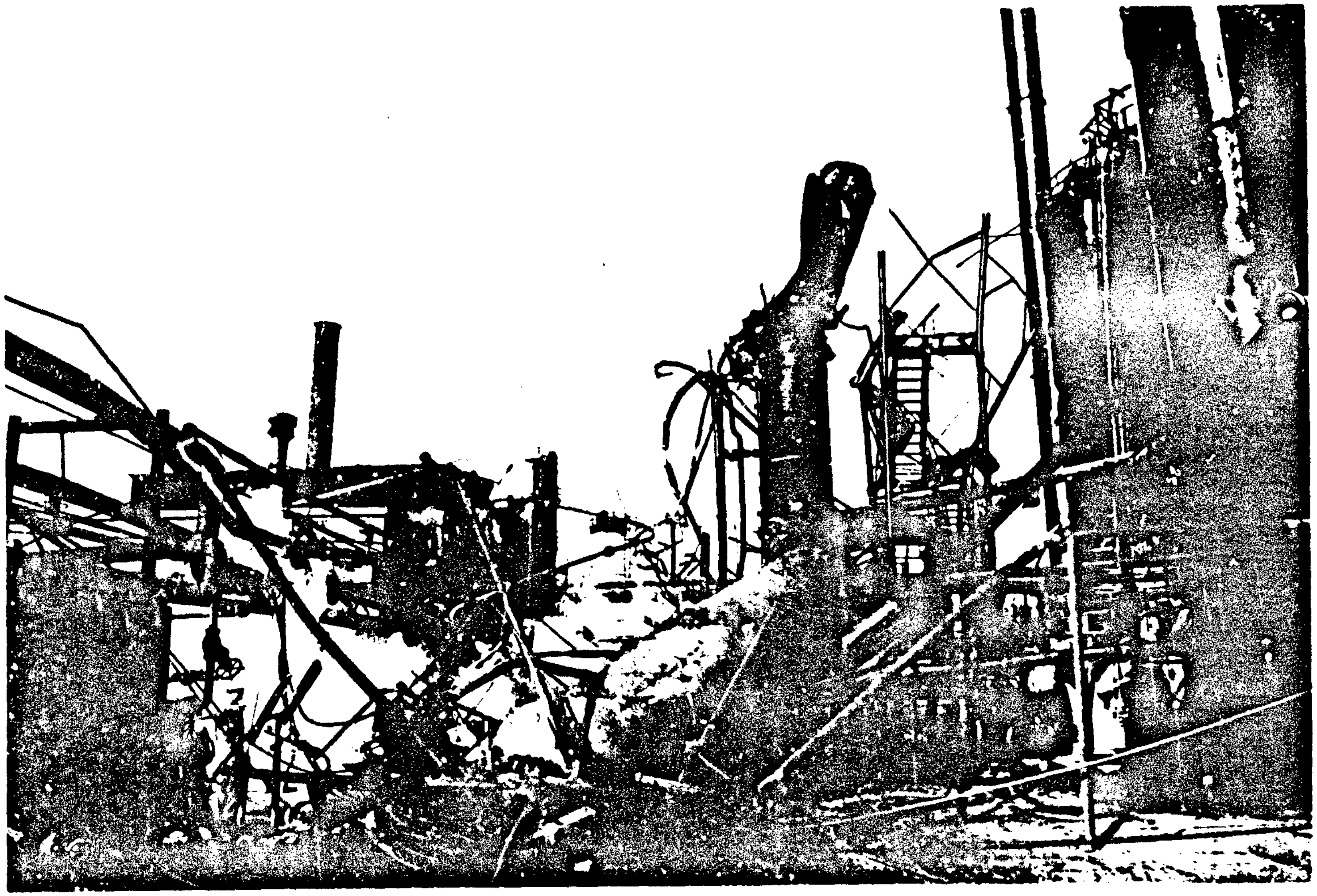


Figure 35. Coking Unit Destroyed by a Detonation on Startup After More Than 30 Years of Operation Involving More Than 6,000 Startups. Dubbs Plant, Ponca City, Okla.

Source; Cities Service Oil Company.

tive energy released assuming equilibrium conditions,- also called dephlagration, and (2) detonations, where conditions are not at equilibrium, the latter reaction occurring at supersonic speeds. Both types of explosions frequently occur in a refinery accident; both cause destruction! In normal explosions, measured peak pressures range upward to 10 times starting pressure; in detonations, up to 700 times have been measured. Detonations react so fast that no safety relief arrangement is able to function before a vessel is blown to bits. Flame fronts traveling at supersonic speeds exert shock waves often having the brisance of nitroglycerine or TNT.

For years, explosive manufacturers have made comparisons between the relatively slow action and pushing nature of a black powder explosion and the instantaneous explosion of nitroglycerine or TNT. The "black powder" type explosion is similar to a normal hydrocarbon explosion, (deflagration), the pushing action of a gasoline-air mixture in an engine or the kerosene-air mixture in a diesel engine. Black powder placed on a boulder does nothing to the rock but shake it. The explosion of a steam boiler or even CO_2 cylinder is quite like the relatively slow action of black powder. Black powder is 75 to 78 percent potassium nitrate, 10 percent sulphur and 15± percent carbon. In coal mining, coal is "pushed" out of its seam in chunks by CO_2 expansion or a slow acting permissable explosive.

A granite boulder can be cracked by mud-capping a stick of dynamite (nitroglycerine composition) and exploding it. The detonation rate of nitroglycerine is 1 ft. in 1/25,000+ of a second; the boulder cannot move out of the way and is cracked. This is an example of detonation, an explosion of high brisance. Both types of explosions can be dangerous and destructive, but detonations are most feared in the refining and natural gas industries because safety valves cannot operate fast enough to relieve explosive pressure.

Some explosives can be detonated by shock waves. Each has an ignition temperature. Robinson[44] points out that the instantaneous pressure of a detonation could be a half-million pounds per square inch. Contrast this to 200 or 300 pounds per square inch pressure of a steam boiler blowup. The detonation rate of 8,500 meters per second curiously enough is 18,000 miles per hour, the speed required by astronauts to leave the earth and go into orbit. There is a relationship between ignition temperature and the drop tests used to test an explosive's sensitivity. Detonation of one explosive may cause the detonation of another when placed close to it. The rate of detonation depends on both the kind of explosive and how tightly it is packed. Robinson continues to point out, "If this wave should hit another mass of explosives while it is still traveling at high velocity, it might have enough energy left in it to initiate detonation in the new mass. When this happens, we call it 'sympathetic detonation', and the explosion of the two masses takes place about as though they had been one mass." Separation by a proper distance is one of the best ways to prevent sympathetic detonations. In the case of 100,000 pounds of high explosives, at least 178 feet of separation are necessary to prevent sympathetic detonation. Figure 36 shows the effect of 100,000 pounds of high explosive on window glass breakage and building damage. In this case, the Ordinance Safety Manual (OSM) indicates that 830 feet between plants is minimum. The crater formed is 65 to 100 feet in diameter and glass breakage could be expected two miles away.

Brasie and Simpson[45] discuss in detail the importance of explosion planning.

"Explosions, detonations, and fires occur annually in all segments of the chemical and petroleum industry. These unfortunate incidents occur in plants- large and small- and occur seemingly, despite the concerted efforts of safety and design engineers, operating personnel and all concerned. Neither years of experience nor size of operation exempt a given plant or company. Hence, like death or taxes, explosions appear inevitable. Whereas no one plans to *have* an explosion, it is highly desirable to plan *for* an explosion.

"The rate of pressure buildup and the peak pressure generated within the exploding system are complex functions of the material involved, its confinement, the detonation or reaction rate, and the available energy per unit volume. For a confined volume of gas, the maximum pressure and time of build-up may be calculated. Pressures of up to 10,000 lb./sq.in. are possible in confined gas explosions. Detonation rates may reach 2,000 to 3,000 ft./sec." High explosives such as nitroglycerine produce maximum pressures of several million pounds/sq/ft-reaction time can exceed 25,000 ft/sec.

Brasie continues,* "In the extreme, nuclear weapons produce pressures which would correspond to temperatures of several million degrees. For this discussion, we need to essentially know that the explosion of detonation process produces extremely rapid, at the point of explosion, a hard core volume of material under extremely high pressure." The mechanics of a nuclear explosion are discussed in detail in Section II.

"The high pressure material expands into the surroundings as a sphere with a spherical shock wave at the front. Depending on the location of the point source, whether it is above ground or at ground, the expanding shock wave behave somewhat differently. An 'air burst' explosion produces additional complications, because of the reflection of the shock wave from ground surfaces. But, in general, the expanding shock wave proceeds out away from the site of the explosion. When the shock wave arrives at a given point, the overpressure brought upon by the shock wave rises to some peak value instantaneously with the arrival of a shock wave. This overpressure at a given point then decays as a function of time, eventually goes negative and finally returns to ambient pressure. The effect is illustrated in Figure 37.

"Behind the shock wave is a region of fast moving air generally moving at above hurricane velocities. This follow-

44 Robinson, Clark Shove "Explosions- Their Anatomy and Destructiveness" McGraw-Hill Book Co., Inc. 1944, page 11

45 Brasie, W. C. and Simpson, D. W. "Guidelines for Estimating Damage Explosion- Loss Prevention"- a CEP technical manual- American Institute of Chemical Engineers Symposium- St. Louis, Missouri, 1968, page 91

*Author's note: This discussion on nuclear bomb force would appear to be out of order and be a part of Chapter IX. It is convenient to include it at this point so that the reader can see a comparison between detonations and nuclear explosions.

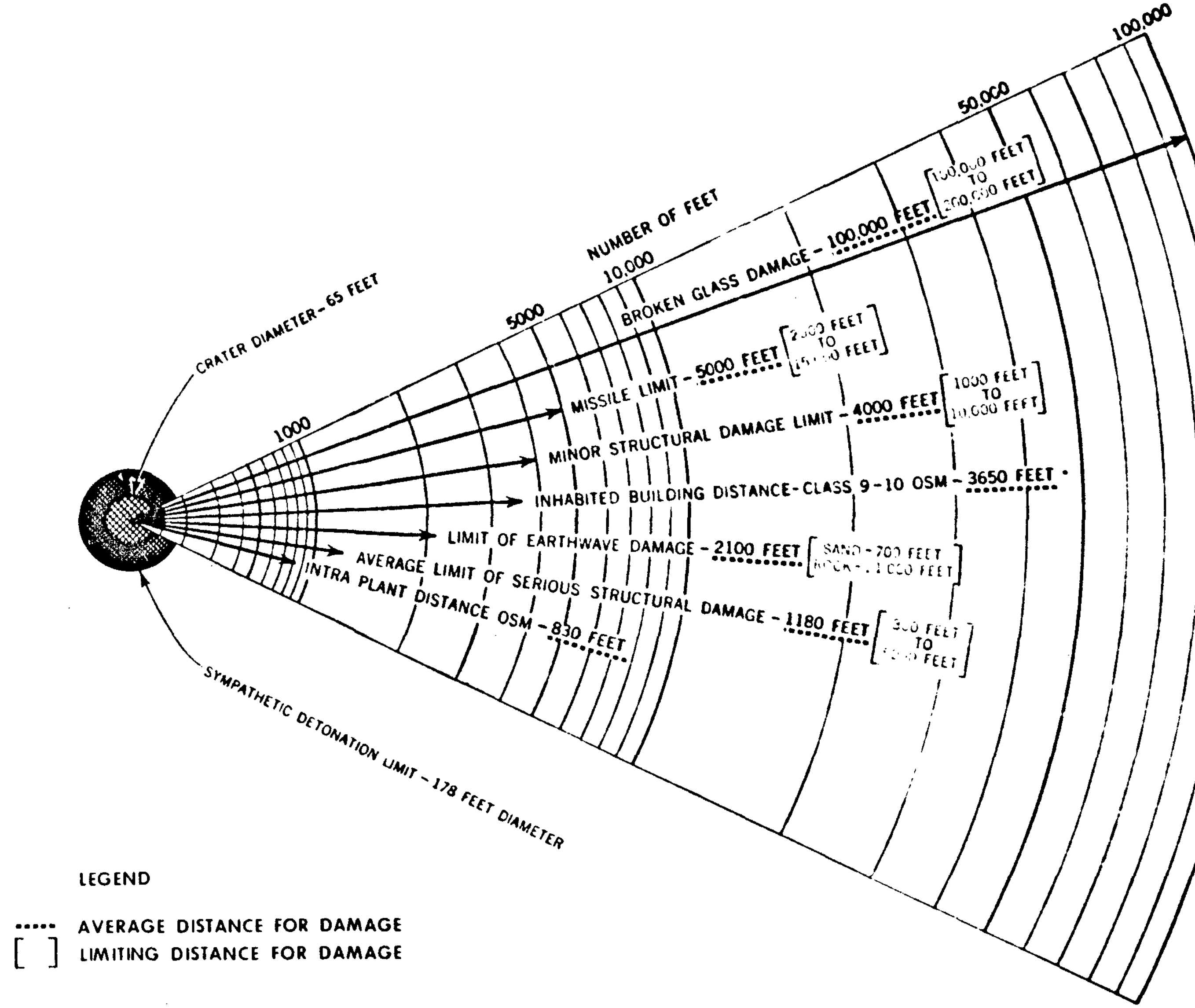


Figure 36. 1000,000 Pounds of High Explosive
Limits of damage from 100,000 pounds of high explosive.
(Source: McGraw-Hill Publishing Co.)

EXPLOSION EFFECTS

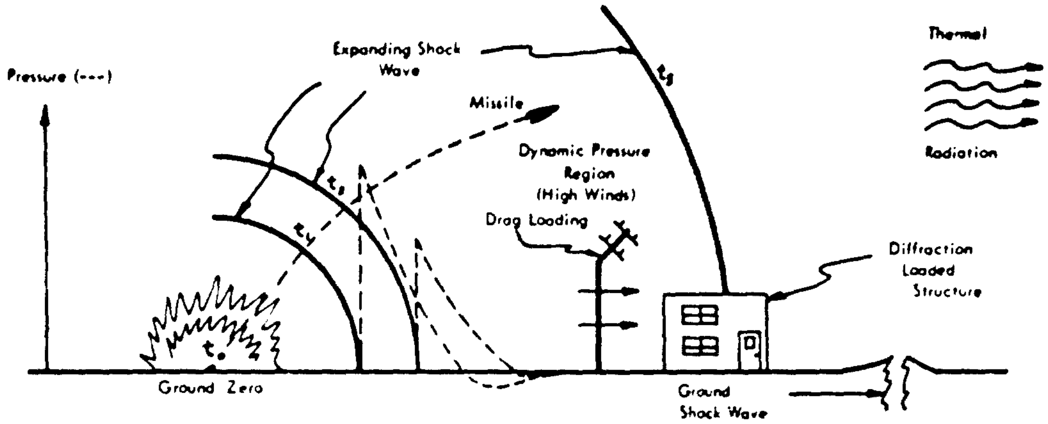


Figure A Qualitative effects of an idealized explosion with respect to time ( ) and distance from ground zero.

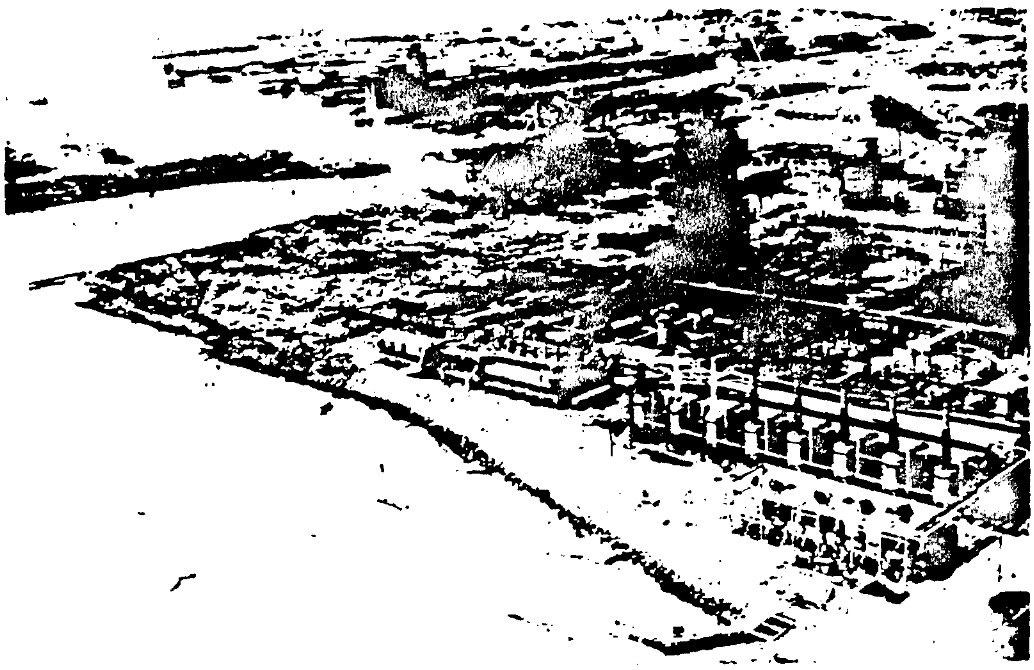


Figure B This illustrates all the significant explosion damage effects. The disaster caused by exploding ammonium nitrate on board two ships has been scaled at about 2.4 KT and involved a nearby chemical process plant, warehouses, grain elevator, refinery tankage, and many residences. Crater (water filled) at center left edge; massive diffraction loading damage to central multi-storied structure 300 ft. distant, complete destruction of warehouses both sides of slips, crushed oil tankage out to 6,000 ft; dynamic loading on foreground structures clearly evident (0.5 to 1.0 lb./sq.in. est.). missile effects including punctured walls and tanks are visible. A one-ton object landed in upper right corner (4,500 ft.). UPI photo.

Figure 37

(Source: AIChE Loss Prevention Symposium[45])

Table 29. Overpressure, Dynamic Pressure, and Wind Velocity in Air at Sea Level for an Ideal Shock Front·

Peak Overpressure (lbs./sq.in.)	Peak Dynamic Pressure (lbs./sq.in.)	Maximum Wind Velocity (mi./hr.)
200	330	2,080
150	223	1,778
100	123	1,414
72	80	1,170
50	40	940
30	16	670
20	8	470
10	2	290
5	0.7	160
2	0.1	70

ing air movement creates what is known as the dynamic pressure. These pressures are equivalent to the stagnation energy· i.e., kinetic energy equivalent, of the winds. Damage to structures is equivalent to that from high winds, i.e., drag loading and negative pressure effects." See Table 29.

Glasstone[46] says, "The dynamic pressure is proportional to the square of the wind velocity and to the density of the air behind the shock front. Both of these quantities may be related to the overpressure under ideal conditions at the wave front by certain equations. For very strong shocks the dynamic pressure is larger than the overpressure, but below 70 pounds per square inch overpressure at sea level the dynamic pressure is smaller. Like the peak shock overpressure, the peak dynamic pressure decreases with increasing distance from the explosion center, although at a different rate. Some indication of the corresponding values of peak overpressure, peak dynamic pressure, and maximum blast wind velocities for an ideal shock front in air at sea level are given in Table 29." Overpressure is pressure created by a blast or wind in excess of normal atmospheric pressure.

Most structural engineers concern themselves with wind loading, the ‹ namic pressure value used in blast damage determinatior . As mentioned in the section on hurricanes, if potential wind velocities were used in areas susceptible to such damage, winds of a minimum of 160 miles per hour* would be a basis for design considerations. Such a wind, easily obtainable in a blast, would have a peak dynamic pressure of 0.7 psig (100 pounds per square foot) and a peak overpressure of 5 psig. Few refinery buildings are built to these specifications. More will be said about overpressure and wind relationships in the nuclear blast section.

Spiegelman[47] and others list tables showing the relative strength and shock wave effect on buildings. See Tables 30, 31, and 32.

All charts and tables assume "table top" condition. Hills and valleys, other buildings, thick woods, loose sand or solid rock (that carries a shock wave)· all could change the effects of a blast.

Referring to Tables 30, 31, and 32 and to Figure 36, one can assess damage and equate it roughly to an equivalent TNT blast.

Brinkley[48] objects to using TNT as a comparison of an explosion yield since for most explosions of concern to the chemical engineer, the assumption is valid.

Brinkley states, "...the design engineer must be concerned with the rational design of protective structures or the rational specifications of separation distances in order to provide protection against blast damage resulting from such explosions.... In order to be useful, it is necessary that the model be a conservative one. As long as it is conservative, it should be as realistic as possible in order to minimize construction costs. It is desirable, therefore, that the model not greatly overestimate the shock wave properties upon which the protective design is to be based." Brinkley considers TNT models applicable only to high intensity explosions; for ideal explosions, it is more non-conservative for overpressure levels of concern to the design engineer, i.e., TNT models relate to detonations.

Explosive and Detonable Mixtures

A review of the nature of explosions is important for the more one understands the causes, the better he can avoid the effects. A study of explosive mixtures always comes down to a study of the chemistry of elements commonly found in crude processing units. Nitrogen, carbon, hydrogen and oxygen, sometimes chlorine and sulphur· here basically are the raw materials for almost any explosive or

46 Glasstone, Samuel "The Effects of Nuclear Weapons" U. S. Department of Defense and U. S. Atomic Energy Commission· Revised Edition· 1964

47 Spiegelman, Arthur "Autopsy of an Explosion" Fire Engineering, October 1967, page 52

*A recent hurricane snapped a guyed flare stack designed for a 200 mph windload.

48 Brinkley, Stuart E., Jr. "Detonation of Explosion Yield of an Exothermic or Detonable Reaction" Loss Prevention Conference· 64th Meeting American Institute of Chemical Engineers· New Orleans, Louisiana· March 1969

Table 30. Air Shock Wave Pressures of TNT

Peak Overpressure in Shock Wave-PSI	Distance (feet) from Known Charge of TNT (pounds) 1 lb.	2 lbs.	4 lbs.	8 lbs.	10 lbs.
85	3	3.8	4.8	6	7.5
45	4	5.0	6.4	8	10
30	5	6.3	8.0	10	12
20	6	7.6	9.6	12	15
14	7	8.8	11.0	14	18
11	8	10.1	13.0	16	20
7	11	14.0	17.5	20	25
4.9	12	16	20	25	32
3.5	15	19	24	30	38
2.2	20	25	32	40	50
1.8	25	32	40	50	64
0.8	50	63	80	100	126
0.40	100	126	160	200	252
0.33	125	158	200	250	316

After Spiegelman[47]

Table 31. Robinson's Damage-Distance Relations.

(Basis: one pound of TNT)

Damage Effect	Distance-Ft. Min.	Ave.	Max.	Average Overpressure-lb./sq.in.
Ground Zero	0	0	0	Approx. 7,500
Crater Diameter		2.2		280
Limit Serious Structural Damage	6.65	26.2	111	2.3
Limit Earthwave Damage	15.5 (1)	46.5	465 (2)	1.2
Inhabited Building Class 9-10 OSM		81		0.45
Limit Minor Structural Damage	22.1	89	221	0.4
Missile Limit	44.5	111	333	0.3
Broken Glass Damage	220	2,200	4,400	0.006 (3)

(1) Sand (2) Rock (3) Considered unrealistically low

flammable mixture one wishes to make. Van Dolah[49] says, "The explosive power of mixtures of nitric acid fuel systems has been recognized in the explosive fraternity for many years." Helhoffite, 28 parts nitrobenzine and 72 parts nitric acid and dithekite, 24 parts nitrobenzine and 63 parts nitric acid are extremely sensitive as is glyceryltrinitrate (nitroglycerine) which is $C_3H_3(ONO_2)_3$. Van Dolah indicates that nitric acid systems form detonable materials, and explosion hazards of nitration reactions have been recognized since Nobel blew up his factory in 1864. The use of nitric acid in the refining and petrochemical industry is now quite common practice.

49 Van Dolah, P. W. "Detonation Potential of Nitric Acid Systems" Loss Prevention Symposium- 64th Meeting of American Institute of Chemical Engineers, New Orleans, La. March 1969

Table 32. Conditions of Failure of Peak Overpressure-Sensitive Elements
Effect of Shock Waves on Buildings

Structural Element	Failure	Approx. Incident Blast Overpressure lb./sq. in.
Glass windows, large and small.	Shattering usually, Occasional Frame failure	0.5 1
Corrugated asbestos siding.	Shattering	1-2
Corrugated steel or aluminum paneling.	Connection failure followed by buckling	1-2
Wood siding panels, standard house construction.	Usually failure occurs at the main connections allowing a whole panel to be blown in.	1-2
Concrete or cinder-block wall panels 8 in. or 12 in. thick (not reinforced)	Shattering of the wall	2-3
Self-framing steel panel building.	Collapse	3-4
Oil storage tanks	Rupture	3-4
Wooden utility poles	Snapping failure	5
Loaded rail cars	Overturning	7
Brick wall panel, 8 in. or 12 in. thick (not reinforced)	Shearing and flexure failures	7-8

From Glasstone- Effects of Nuclear Weapons[12]

Nitrogen alone can be totally inert, or it can loosely combine itself into a compound that could blow the top off almost anything. If when inerting or purging with nitrogen a condition exists with air present, and nitric acid can be formed in the presence of a complex group of hydrocarbons and catalysts, there is some question as to what might possibly be created. The formation of even a small amount of sensitive material could possibly trigger a greater reaction in a less sensitive atmosphere. Certainly, reactions purposely using nitric acid and hydrocarbons together need very special attention, for during the nitration of hydrocarbons either intentionally or accidentally, explosives can form.

A college chemistry text teaches that the Haber process for making ammonia combines nitrogen with hydrogen usually in the presence of an iron-molybdenum catalyst to help the reaction along. The reaction of nitrogen and hydrogen occurs at less than 200° C. and causes a liberation of 24,000 calories of heat under normal pressure. Considering the materials present, the creation of a number of unstable compounds seems possible in an improperly controlled reactor, especially if contamination occurs.

A case is known where a catalytic desulfurization unit had a coke build-up on the catalyst bed and was being readied for clean-out. When the reactor was purged with nitrogen, supplied by a local vendor, the temperature of the reactor bed rose 20-30° F. from an initial temperature of 610° F. Effluent gas tested 5% combustibles. Everything seemed tight and no air leak was found. The second cycle continued-still a pick-up in temperature. By the fourth purge, temperature at the top of the reactor bed reached 1000° F.- then rapidly went 1440° F. as the nitrogen purge continued. Everything was instantly stopped. Gas samples from the reactor showed 20% CO_2 and 0.9% NH_3. A check of the nitrogen tanks showed 16.9% oxygen in one and 22.3% oxygen in another. *This "nitrogen" was air!* Fortunately a detonation was not triggered.- But how close! An oxygen trailer had accidentally been used for the nitrogen. Constant monitoring of oxygen content of inert gas for purging is important.

Much research needs to be done in order to find the answers to such questions as: Under certain conditions, is it possible that some stronger or more sensitive explosive

which has combined in a reactor or vessel, caused or started a detonation? Or, are we dealing only with a turbulent hydrocarbon mixture capable of detonating with the force equal to that of detonating nitroglycerine?

What part does iron sulphide play in accidents? Many cases are known where great heat has been generated by the drying out of iron sulphide enough to trigger an explosion. There must be many possible causes of detonations and explosions. Why do some flammable mixtures explode while others do not? See Figure 38.

Jacobs[2] discusses detonations in the following excerpts. ......Until rather recently it was generally thought that gaseous detonations were largely confined to rapid burning mixtures which would include:

1. Hydrogen with oxygen or air
2. Unsaturated hydrocarbons with oxygen or air
3. Saturated hydrocarbons with oxygen.

"In addition, it was known that saturated hydrocarbons and air would detonate if these were in a highly turbulent condition. This knowledge resulted from some experimental work following up on a number of pipeline explosions where an unusual degree of violence was exhibited.

"Now we believe that almost all flammable gaseous hydrocarbon-air mixtures can detonate. Furthermore, we know that flammable hydrocarbon mists in air will also detonate, although only two or three years ago lively debates were held on the subject of whether hydrocarbon mists in air were capable of anything more destructive than slow burning.

"As indicated herein, we do not know precisely under what conditions any mixture will detonate. With considerable trepidation then, we suggest the tentative geometric criteria shown in Table 33. It is hoped that further investigation in this area will result in criteria which are much more reliable and exact. It is emphasized that the criteria given apply only to saturated hydrocarbon types beginning at atmospheric conditions in a nonturbulent state. Apparently if a high degree of turbulence is present, only a few feet are required for the development of intense shock waves. Furthermore, if unsaturated hydrocarbons or hydrogen are involved, or if the air is enriched with oxygen, detonations proceed much more readily than indicated. Also higher pressures and lower temperatures promote detonations.

Table 33. Tentative Criteria for Detonation of Gaseous Hydrocarbon-Air Mixtures*

Diameter of Vessel (Feet)	Minimum Length (Feet)**
Less than 1	10
1 to 3	40
Greater than 3	25

*For saturated hydrocarbon types starting at atmospheric, nonturbulent conditions.

**Length inversely proportional to (pressure); length directly proportional to (temperature).

After Jacobs

Conversely, a depletion of oxygen or a higher temperature or a lower pressure make detonation more unlikely."

Ginsburgh and Bulkley[50] studied detonations in 2 inch test pipes to determine distance relationships of flammable mixtures and detonations. They state, "The ease of detonability of combustible gases in air is defined by their detonation induction distances, which are important criteria in evaluating hazards in industrial equipment. Even in the absence of a stable detonation, an abnormally high pressure and a steep shock front are of critical importance to process safety considerations. Because of the safety factors that are applied in industrial practice, only approximate values of the detonation criteria are needed. This fact permits considerable simplification in experimental technique."

Ginsburgh and Bulkley conclude:

1. Induction distance is long and the initiation of detonation is marginal for mixtures in which burning velocity is below 2.5 ft./sec.

2. Initial pressure has little effect on induction distance for those slow-burning mixtures.

3. The detonation hazard is increased by any factor that increases burning velocity. Methane-air mixtures do not detonate under normal conditions, but they can detonate when burning velocity is increased by severe turbulence.

4. For burning velocities between 2.5 and 20 ft./sec. induction distance decreases with increasing burning velocity and also is a function of initial pressure. Above 20 ft./sec., neither pressure nor burning velocity has appreciable effect on induction distance.

5. A detonation once started in a pipe line, multiple detonations can occur.

Ginsburgh and Bulkley continue, "Design of industrial equipment to withstand a detonation normally is economically impossible. With the exception of small piping, which may have adequate strength with normal wall thickness, vessels and other components would require impractical overdesign. Containment probably will become more difficult as processing pressures increase. Fortunately, the low detonability of many hydrocarbon-air mixtures at low or moderate pressures permits conventional equipment designs to continue in many instances. However, care must be taken to avoid long runs of piping where any flammable mixture can occur normally or inadvertently. Entrant piping on vessels, particularly with large sizes, must be considered carefully to ensure that conditions favorable for a spherical detonation do not exist.

"Evaluation and prevention of industrial detonation hazards improve with a better understanding of the mechanism. However, with present technology, uncertainties exceed the risk level permissable in many operations. Except in the few cases in which piping and equipment can be designed to avoid or contain detonations, complete elimination of flammable mixtures is the only presently acceptable protection against detonation damage in process facilities."

Table 34 is the result of their experiments.

To further understand the nature of detonations and indeed normal explosions also, the extensive work of the

50 Ginsburgh, I. and Bulkley, W. L. - Hydrocarbon-Air Detonations... Industrial Aspects- Chem. Eng. Progress- Feb. 1963, p. 82

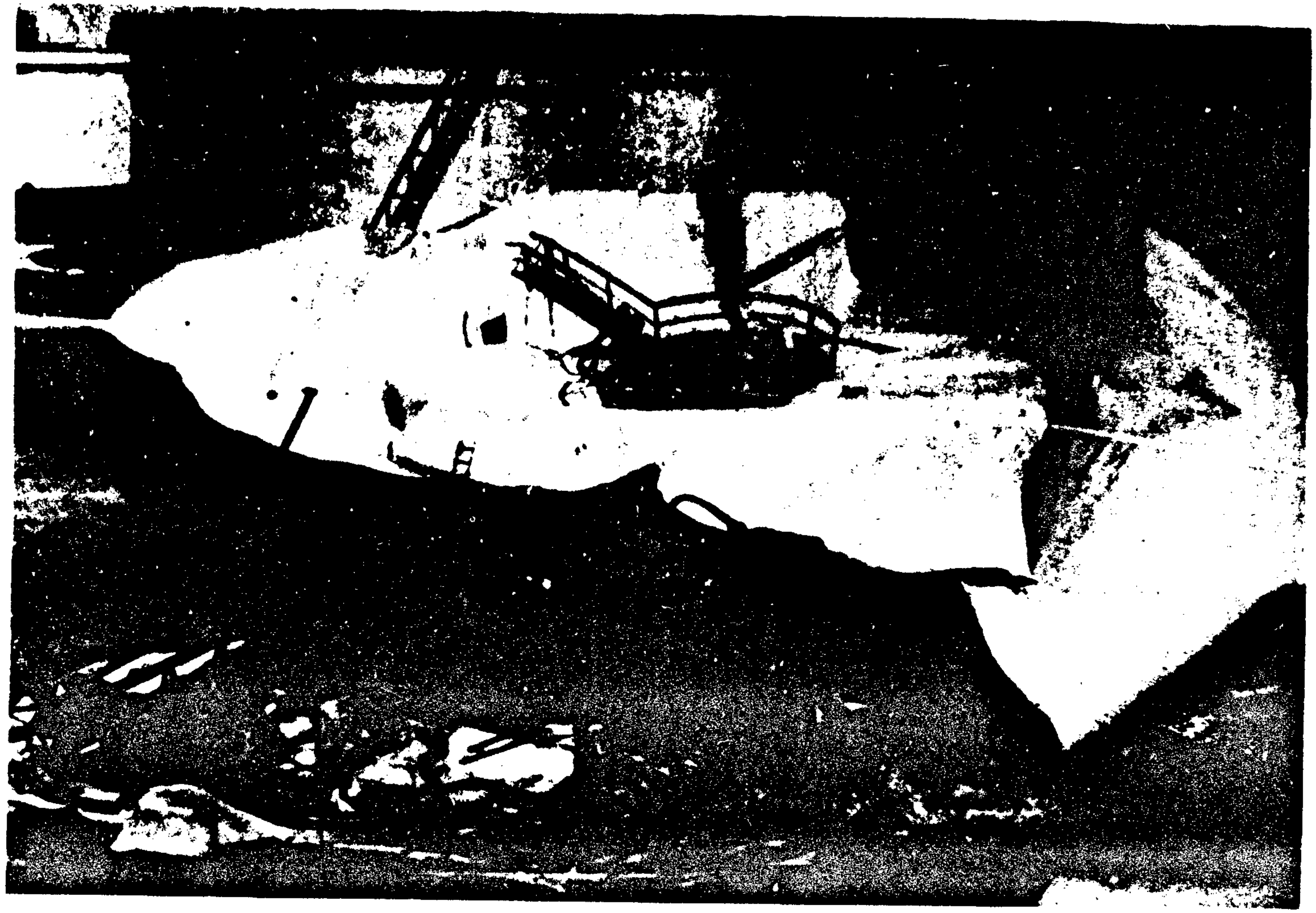


Figure 38. Spheriod ruptured by a low-order explosion and further damaged by the outrush of water through the initial fracture. The vessel was being emptied after filling and overflowing with water. Evidently, hydrocarbons had not been entirely displaced and were floating on the surface of the water. The hydrocarbons vaporized, mixed with air being drawn through the vent, and were ignited by sulfide deposits.

(Source: American Oil Co.)

Table 34. Detonation Induction Distance in 2-in. Pipe

	Mixture Compositions- %			Int. Press.	Dist.
Fuel	Fuel	O_2	N_2	Atm.	Ft. (a)
H_2	29	Air		2	16
H_2	29	Air		3	14
H_2	29	Air		5	11
H_2	29	Air		13	14
CH_4	6	Air		2	16
CH_4	6	Air		4	18
CH_4	6	Air		5	14
CH_4	6	Air		8	18
C_2H_4	6	Air		13	14
C_2H_4	12	36	52	2	8
C_2H_4	12	36	52	3	6
C_2H_4	12	36	52	5	6
C_3H_8	16	84	—	4	1
C_3H_8	16	84	—	2	1
C_3H_8	5	Air		4	21
C_3H_8	5	Air		4	46
C_3H_8	5	Air		7	59
NH_3	35	51	14	1	10
NH_3	29	44	29	1	16
NH_3	40	60	—	1	8
NH_3	40	60	—	1	14 (4-in. pipe)
NH_3	40	60	—	4	8
NH_3	22	Air		1	>100
CH_4	9.5	Air		1	>100

(a) Detonation induction distance

Bureau of Mines should be reviewed. Only a very small portion of their efforts is discussed here. Zabetakis[51] discusses explosive mixtures. In explaining the detonation process he states, "....once a flammable mixture is ignited, the resulting flame, if not extinguished, will either attach itself to the ignition source or propagate from it. If it propagates from the source, the propagation rate will be either subsonic (deflagration) or supersonic (detonation) relative to the unburned gas. If it is subsonic, the pressure will equalize at the speed of sound throughout the enclosure in which combustion is taking place so that the pressure drop across the flame (reaction) front will be relatively small. If the rate is supersonic, the rate of pressure equalization will be less than the propagation rate and there will be an appreciable pressure drop across the flame front. Moreover, with most combustible air mixtures at ordinary temperatures, the ratio of the peak-to-initial pressure within the enclosure will seldom exceed 8:1 in the former, but may be more than 40:1 in the latter case. The pressure build-up is especially great when detonation follows a large pressure rise due to deflagration. The distance required for a deflagration to transit to a detonation depends on the flammable mixture, temperature, pressure, the enclosure, and the ignition source. With a sufficiently powerful ignition source, detonation may occur immediately upon ignition, even in the open. However, the ignition energy required to initiate a detonation is usually many orders of magnitude greater than that required to initiate a deflagration."

In discussing the limits of flammability, Zabetakis continues, "A combustible gas-air mixture can be burned over a wide range of concentrations – when either subjected to elevated temperatures or exposed to a catalytic surface at ordinary temperatures. However, homogeneous combustible gas-air mixtures are flammable - that is, they can propagate flame freely within a limited range of compositions. For example, trace amounts of methane in air can be readily oxidized on a heated surface, but a flame will propagate from an ignition source at ambient temperatures and pressures only if the surrounding mixture contains at least 5 but less than 15 volume-percent methane. The more dilute mixture is known as the lower limit, or combustible-lean limit, mixture; the more concentrated mixture is known as the upper limit, or combustible-rich limit, mixture. In practice, the limits of flammability of a particular system of gases are affected by the temperature-pressure direction of flame propagation, gravitational field strength, and surroundings. The limits are obtained experimentally by determining the limiting mixture compositions between flammable and nonflammable mixtures."

Table 35 lists properties and flammable limits of hydrocarbons most common to a refinery operation. Each has its ignition temperature which varies as shown in Figures 39 and Table 36. Many explosive mixtures can be ignited by a spark of low energy content but of a large power density. (See Reference 51, page 3.) There is still much to learn about ignition processes also. Of immediate interest is the lowest temperature at which ignition can occur. This is the auto-ignition (AIT) or spontaneous-ignition temperature. In the "fire" triangle of Figure 40, elimination of any leg of the triangle (or three legged stool, as you wish) prevents a fire, explosion, or detonation. Temperatures below the auto-ignition temperature remove ignition potential for that mixture. It is well understood that basic fire control principles include removal of any one or two of the legs of the triangle to stop a fire or prevent one.

As the temperature of hydrocarbon gases increases, the hydrocarbon in air flammable limit is lowered, as portrayed in Figure 39. Tables 36 and 37 list the flammable limits of common hydrocarbons and petrochemicals.

Some investigators believe that in turbulent conditions, detonation is most likely to occur in the lower hydrocarbon-air flammable mixture range, other conditions being also favorable.

Flammable limits in oxygen are about the same as in air.

In a review of fire and explosion hazards of aviation fuels, Van Dolah et al[52] summarize the effects of temperature and pressure as follows:

---

51 Zabetakis, Michael G.- Flammability Characteristics of Combustible Gases and Vapors- U.S. Bureau of Mines Bull. 627, 1965- TN23U4 No. 627 622.06173

52 Van Dolah, Robt. W., Zabetakis, Michael G., Burgess, Davis S., Scott, George S.- Review of Fire and Explosion Hazards of Flight Vehicle Combustibles- U.S. Bureau of Mines Inf. Circ. 8137- 1963- p. 16

Table 35. Properties of Paraffin Hydrocarbons

Combustible	Formula	M	Sp gr (Air=1)	C_{st} in air (vol pct)	Net ΔH_c $\left(\frac{\text{Kcal}}{\text{mole}}\right)$	Lower limit in air: L_{25} (vol pct)	$\frac{L_{25}}{C_{st}}$	L $\left(\frac{\text{mg}}{1}\right)$	Ref.*	Upper limit in air: U_{25} (vol pct)	$\frac{U_{25}}{C_{st}}$	U $\left(\frac{\text{mg}}{1}\right)$	Ref.*
Methane	CH_4	16.04	0.55	9.48	191.8	5.0	0.53	31	*(40)*	15.0	1.6	126	*(40)*
Ethane	C_2H_6	30.07	1.04	5.65	341.3	3.0	.53	41	*(40)*	12.4	2.2	190	*(41)*
Propane	C_3H_8	44.09	1.52	4.02	488.5	2.1	.52	42	*(115)*	9.5	2.4	210	*(41)*
n-Butane	C_4H_{10}	58.12	2.01	3.12	635.4	1.8	.58	48	*(113)*	8.4	2.7	240	*(41)*
n-Pentane	C_5H_{12}	72.15	2.49	2.55	782.0	1.4	.55	46	*(40)*	7.8	3.1	270	*(40)*
n-Hexane	C_6H_{14}	86.17	2.98	2.16	928.9	1.2	.56	47	*(246)*	7.4	3.4	310	*(40)*
n-Heptane	C_7H_{16}	100.20	3.46	1.87	1075.8	1.05	.56	47	*(246)*	6.7	3.6	320	*(40)*
n-Octane	C_8H_{18}	114.23	3.94	1.65	1222.8	.95	.58	49	*(246)*	–	–	–	–
n-Nonane	C_9H_{20}	128.25	4.43	1.47	1369.7	[1].85	.58	49	*(246)*	–	–	–	–
n-Decane	$C_{10}H_{22}$	142.28	4.91	1.33	1516.6	[2].75	.56	48	*(246)*	[3]5.6	4.2	380	–
n-Undecane	$C_{11}H_{24}$	156.30	5.40	1.22	1663.6	.68	.56	48	(1)	–	–	–	–
n-Dodecane	$C_{12}H_{26}$	170.33	5.88	1.12	1810.5	.60	.54	46	(4)	–	–	–	–
n-Tridecane	$C_{13}H_{28}$	184.36	6.37	1.01	1957.4	.55	.53	46	(4)	–	–	–	–
n-Tetradecane	$C_{14}H_{30}$	198.38	6.85	.97	2104.3	.50	.52	44	(4)	–	–	–	–
n-Pentadecane	$C_{15}H_{32}$	212.41	7.33	.90	2251.2	.46	.51	46	(4)	–	–	–	–
n-Hexadecane	$C_{16}H_{34}$	226.44	7.82	.85	2398.2	.43	.51	44	(4)	–	–	–	–

[1] t=43°C.
[2] t=53°C.
[3] t=86°C.

[4] Calculated value extrapolated to 25° C at Explosives Res. Center, Federal Bureau of Mines.

*See paper cited for references.

(Source: Zabetakis, USBM.)

"The system temperature is of importance in flammability in that it affects vapor pressures, reaction rates, and final product temperatures and therefore the limits of flammability, flame speeds, and tendency to auto-ignite. As noted earlier, an increase in the temperautre produces a widening in the flammable range of mixture compositions; if the temperature of a flammable mixture is increased sufficiently, the mixture will ignite spontaneously.

"Pressure also affects the reaction rate of a chemical reaction and therefore also the limits of flammability, flame speeds, and the tendency to auto-ignite. A large increase in pressure usually widens the flammable range and decreases the temperature required for auto-ignition. However, the converse appears to be true with some high-energy fuels. Further, a decrease in pressure results in increased ignition energy requirements and ultimately leads to a condition in which flame propagation does not occur in a particular confining vessel.

"Since the vapor pressure of a combustible is primarily dependent on the temperature, a decrease in the ambient pressure results in a decrease in the flashpoint even though the limits of flammability are not affected appreciably by small pressure changes. Accordingly, liquids with flash-points above room temperature at 1 atmosphere pressure, may form flammable mixtures at reduced pressures.

Burning rates of solids are also pressure dependent. Klein[53] has found that in an atmosphere of fixed composition (for example, air), the burning rate of cotton fabric decreases as the pressure decreases. Similarly, the burning rate decreases with decrease in oxygen concentration at any given total pressure, but increases with decrease in pressure for a given oxygen partial pressure when nitrogen is used as the diluent.

An understanding of the above principles not only aids design engineers, but also gives refinery operators an understanding of fires and explosions which can happen and how to prevent them. Fire fighters also need to understand these fundamentals.

Space Explosions- Hydrogen Release- Not all refinery accidents are detonations, yet an explosion can work into a detonation. Minor explosions are quite common and are usually controllable. An understanding of the flammable mixture of the gases is essential. So often a small explosion causes enough turbulence and heat to create a detonation. A fire nearly always follows.

Since space explosions are somewhat different than blasts from equipment failure, and since a mass of gas can travel

53 Klein, Howard A. "The Effects of Cabin Atmosphere on Combustion of Some Flammable Aircraft Materials" WADC Technical Report 59-456 April 1960

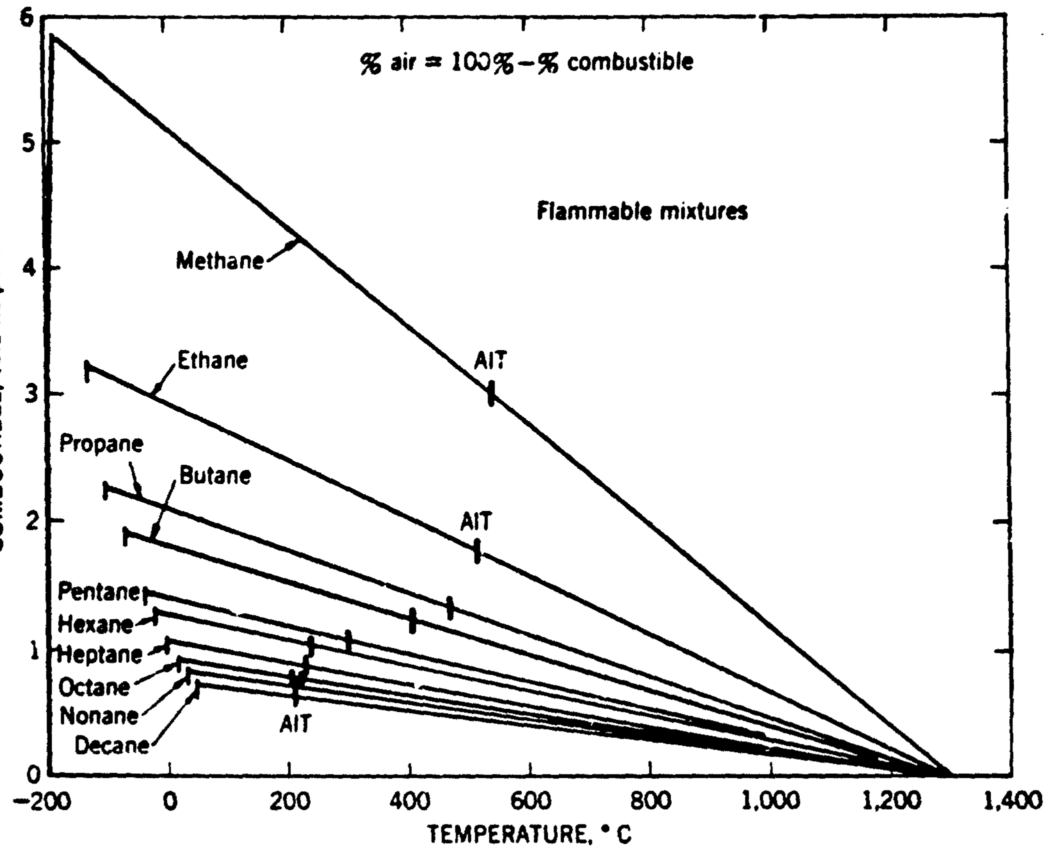


Figure 39. Effect of Temperature on Lower Limits of Flammability of 10 Paraffin Hydrocarbons in Air at Atmospheric Pressure.
(Zabetakis, US BofM[51])

with the wind before detonation, the nature of such explosions needs to be discussed.

Bradford and Culbertson[54] state the following: "Explosions after widespread flammable vapor releases have resulted in development of high blast pressures and considerable structural damage. For example, the ethylene leak in a plant in Germany demonstrated this loss potential. Ethylene from a pipe failure traveled about 200 feet before reaching a source of ignition. The centralized control house located about 75 to 100 feet from the ethylene plant had brick walls with laminated safety glass windows.

"The space explosion blew in windows and walls rendering the control house inoperative. It was estimated after the explosion that a force equal to 2 or 3 tons of TNT was released at blast pressure." Other plants have also experienced space explosions where results of high pressure on structures were observed. Humble Oil and Refinery Co.'s Baytown Refinery, in a refinery explosion analysis, noted some refinery explosions equivalent to over 10 tons of TNT.

An incident involving hydrogen released in the air in Jackass Flats, Nevada,[55] in 1954, showed measurable overpressure when ignition occurred. It was estimated that 200 lbs. of hydrogen burned and the flame speeds rose rapidly above normal speeds, although much lower than detonation velocity. Spontaneous ignition occurred at a flow rate of 125,000 lbs./hr. The volume involved in the explosion was 30' diameter x 150' high- about 200 lbs. A 0.5 psi pressure was measured 200' away. The resultant blast damage approximated that of 60 lbs. of TNT.

Some of Bradford and Culbertson's work refers to the Bulkley and Jacob's paper.[56] This paper brings attention to the spontaneous ignition tendency of a free hydrogen release and the possible blast pressures on refinery buildings. They state, "In these days of 40,000 bbls./day reformers and hydrocrackers, and 1500 tons/day ammonia plants, we have entered a new era where the quantities of hydrogen in-

54 Bradford, W. J. and Culbertson, T. L. "Design of Control Houses to Withstand Explosive Forces" American Institute of Chemical Engineers Meeting- Houston, Texas February 1967

55 Reider, Roy; Otway, H. J.; Knight, H. T. "An Unconfined, Large Volume Hydrogen/Air Explosion" Pyrodynamics- 2- 249-269 1965

56 Bulkley, Wm. L. and Jacobs, R. B. "Hazard of Atmospheric Releases of Large Volumes of Hydrogen" API Facilities Subcommittee- Oct. 4, 1966

Table 38. Lower Temperature Limits and Autoignition Temperatures of Paraffin Hydrocarbons at Atmospheric Pressure

	Lower temperature limit In air			Autoignition temperature In air			Autoignition temperature In oxygen		
	°C	°F	Ref.*	°C	°F	Ref.*	°C	°F	Ref.*
Methane	−187	−305	(¹)	537	999	*(158)*	–	–	–
Ethane	−130	−202	(¹)	515	959	*(237)*	506	943	*(94)*
Propane	−102	−152	(¹)	466	871	*(158)*	–	–	–
n-Butane	−72	−96	(¹)	405	761	*(237)*	283	542	*(191)*
Isobutane	−81	−114	(¹)	462	861	*(158)*	319	606	*(94)*
n-Pentane	−48	−54	(¹)	258	496	*(194)*	258	496	*(144)*
n-Hexane	−26	−15	*(159)*	223	433	*(194)*	225	437	*(94)*
n-Heptane	−4	25	*(159)*	223	433	*(237)*	209	408	*(94)*
n-Octane	13	56	*(159)*	220	428	*(237)*	208	406	*(191)*
n-Nonane	31	88	*(159)*	206	403	*(237)*	–	–	–
n-Decane	46	115	*(159)*	208	406	*(237)*	202	396	*(94)*
n-Dodecane	74	165	*(159)*	204	399	*(237)*	–	–	–
n-Hexadecane	126	259	(¹)	205	401	*(237)*	–	–	–

¹Caculated value.

Source: Zabetakis, USBM.

*See publication cited for data reference.

volved are vastly greater than those to which we have been accustomed. Emergency release of these large volumes of hydrogen into the atmosphere may create a greater hazard potential in two ways:

(1) The greater quantity of combustible material present in a single, atmospheric cloud increases the magnitude of the possible thermal energy release and consequently the potential damage severity.

(2) The increase in the size of the combustible volume also increases the possibility of ordinary burning developing into a detonation with its attendant possibility of severe damage."

There are a number of instances where volumes of hydrogen have been quickly released.

The German Von Hindenberg transoceanic dirigible disaster happened as hydrogen was being valved off. This tragic event forewarned of future problems. In another case studied, as little as 10 pounds of hydrogen has spontaneously ignited when released from under pressure. There appears to be many pros and cons about purposely igniting primarily because of the wide difference in hydrocarbon content, velocity, wind, height of ignition and other variables.

Bulkley and Jacobs conclude:

1. The shock wave from 10 pounds of hydrogen would likely cause serious structural damage to a building such as a control house at a distance of 150 feet or less. (We need to be concerned if the hydrogen release exceeds 10 pounds.) See Figure 41.

2. Hydrogen release into the atmosphere tends to consistently ignite in absence of any apparent source of ignition.

3. One pound of hydrogen, burned with adequate oxygen, has a potential blast damage effect equivalent to about 5 pounds of TNT if detonation occurs in the hydrogen-air mixture. (Some research men place the value higher).

4. If the quantity of hydrogen exceeds 10 pounds, there is a possibility of damage if the rate of hydrogen release is above the range 4,000 to 18,000 pounds per hour. In some units emergency release could be in the range of 50,000 to 150,000 pounds per hour. Reider, et al.[55] suggest flaring hydrogen when normal release exceeds 3,600 pounds per hour.

5. The size of the hydrogen-air volume required for the development of detonation using ordinary ignition sources must have dimensions in the order of 30 feet. Bulkley and Jacobs estimate that discharges of 25,000 to 30,000 pounds per hour rate will have this dimension. (subject to further study).

6. Hydrocarbons narrow flammable limits, reduces burning rates, and increases the volume necessary for detonation-the hydrocarbon does increase the available energy.

7. The heat release of 10^9 Btu per hour (about 20,000 pounds of hydrogen per hour), a stack about 100 feet high gives tolerable ground level radiation; with a hydrocarbon content in the released hydrogen, the stack needs to be higher.

Gealer and Churchill,[57] in the study of hydrogen-oxygen mixtures, discuss an interesting feature of a detonation

57 Gealer, Roy L. and Churchill, Stuart W. "Detonation Characteristics of Hydrogen-Oxygen Mixtures at High Initial Pressures" American Institute of Chemical Engineers Journal- Vol. 6, No. 3, Sept. 1960

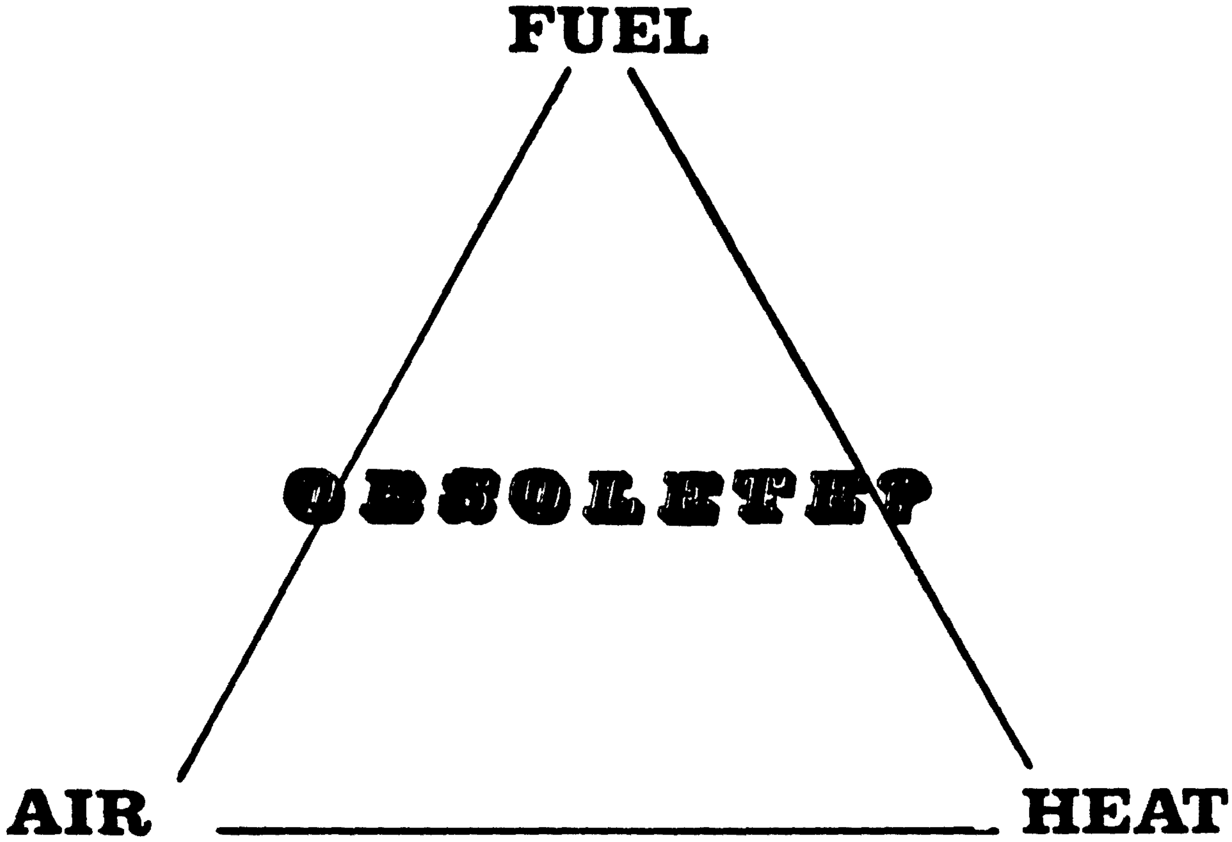


Figure 40. One Might Ask, is the Air-Fuel-Heat Triangle Obsolete? Modern Processes are Required to Work within these Conditions.

wave. "When a detonation collides with a solid wall, a reflected wave travels back through the burned gases. This reflected wave produces a second pressure rise, and the resulting pressure is often called *impact pressure!!*"

In some cases this wave can be amplified substantially; it is not necessary to multiply a detonation shock wave to come into pressure ranges typical of those created by a small bomb.

Bradford and Culbertson[54] discuss the problem of predicting explosive forces from space explosions: "Attempts to predict the explosion forces which may result from hydrocarbon space explosions are difficult. Many important variables such as area and extent of diffusion (dependent on wind condition and method of release), quantity of material involved, point of ignition, degree of confinement by buildings and equipment are unknown. Based on experience, the Bureau of Mines has suggested the following to obtain the order of magnitude of a space explosion: Multiply 10% of the heat of combustion in Btu/lb. of the hydrocarbon by the quantity of material which may be released in 30 seconds. Divide the resultant figure by 2000 to obtain the theoretical explosion yield in pounds of TNT. The 10% figure is a conservative estimate of the heat released by burning which results in blast damage. The 30 second release figure is an estimate of the quantity which would be in the flammable range. The energy of explosion from a pound of TNT is 2000 Btu."

"As an example, if we assume an extreme case of an area 200 x 200 x 10 ft. high containing a stoichiometric concentration of ethane in air (5%), we would have 24,000 cu. ft. or 2000 lbs. of ethane. With a heat of combustion of 20,000 Btu/lb. and the conservative 10% available for explosive yield, we could get 4,000,000 Btu of blast energy. This is equivalent to 1 ton of TNT. This mass acting 100 ft. from a building would result in 15 psig side-on overpressure and a reflective overpressure of 45 psig, according to work done by the Department of Defense's Ballistic Research Laboratory."

In order to avoid danger of a sudden leak, spillage or otherwise release of hydrogen by accident, Zabetakis and Burgess[58] suggest the spacing shown in Table 38 for minimum distances between storage of liquid hydrogen and buildings and tanks.

58 Zabetakis, M. G. and Burgess, D. S. "Research on the Hazards Associated with the Production and Handling of Liquid Hydrogen" U. S. Bureau of Mines RI5707- U. S. Department of the Interior 1961

Table 37. Summary of Limits of Flammability, Lower Temperature Limits (T_L), and Minimum Autoignition Temperatures (AIT) of Individual Gases and Vapors in Air at Atmospheric Pressure

Combustible	Limits of flammability (volume-percent)*		T_L (° C)	AIT (° C)
	L_{25}	U_{25}		
Acetal	1.6	10	37	230
Acetaldehyde	4.0	60	–	175
Acetic acid	[1]5.4	–	40	405
Acetic anhydride	[2]2.7	[3]10	47	390
Acetanilide	[4]1.0	–	–	545
Acetone	2.6	13	–	465
Acetophenone	[4]1.1	–	–	570
Acetylacetone	[4]1.7	–	–	340
Acetyl chloride	[4]5.0	–	–	390
Acetylene	2.5	100	–	305
Acrolein	2.8	31	–	235
Acrylonitrile	3.0	–	–6	–
Acetone Cyanohydrin	2.2	12	–	–
Adipic acid	[4]1.6	–	–	420
Aldol	[4]2.0	–	–	250
Allyl alcohol	2.5	18	22	–
Allyl amine	2.2	22	–	375
Allyl bromide	[4]2.7	–	–	295
Allyl chloride	2.9	–	–32	485
o-Aminodiphenyl	.66	4.1	–	450
Ammonia	15	28	–	–
n-Amyl acetate	[1]1.0	[1]7.1	25	360
n-Amyl alcohol	[1]1.4	[1]10	38	300
tert-Amyl alcohol	[4]1.4	–	–	435
n-Amyl chloride	[5]1.6	[1]8.6	–	260
tert-Amyl chloride	[4]1.5	–	–12	345
n-Amyl ether	[4].7	–	–	170
Amyl nitrite	[4]1.0	–	–	210
n-Amyl propionate	[4]1.0	–	–	380
Amylene	1.4	8.7	–	275
Aniline	[7]1.2	[7]8.3	–	615
Anthracene	[4].65	–	–	540
n-Amyl nitrate	1.1	–	–	195
Benzene	[1]1.3	[1]7.9	–	560
Benzyl benzoate	[4].7	–	–	480
Benzyl chloride	[4]1.2	–	–	585
Bicyclohexyl	[1].65	[8]5.1	74	245
Biphenyl	[9].70	–	110	540
2-Biphenylamine	[4].8	–	–	450
Bromobenzene	[4]1.6	–	–	565
Butadiene (1,3)	2.0	12	–	420
n-Butane	1.8	8.4	–72	405
1,3-Butandiol	[4]1.9	–	–	395
Butene-1	1.6	10	–	385
Butene-2	1.7	9.7	–	325
n-Butyl acetate	[5]1.4	[1]8.0	–	425
n-Butyl alcohol	[1]1.7	[1]12	–	–
sec-Butyl alcohol	[1]1.7	[1]9.8	21	405
tert-Butyl alcohol	[1]1.9	[1]9.0	11	480
tert-Butyl amine	[1]1.7	[1]8.9	–	380
n-Butyl benzene	[1].82	[1]5.8	–	410
sec-Butyl benzene	[1]0.77	[1]5.8	–	420
tert-Butyl benzene	[1].77	[1]5.8	–	450
n-Butyl bromide	[1]2.5	–	–	265
Butyl cellosolve	[8]1.1	[10]11	–	245
n-Butyl chloride	1.8	[1]10	–	–
n-Butyl formate	1.7	8.2	–	–
n-Butyl stearate	[4].3	–	–	355
Butyric acid	[4]2.1	–	–	450
α-Butryolactone	[8]2.0	–	–	–
Carbon disulfide	1.3	50	–	90

Combustible	Limits of flammability (volume-percent)		T_L (° C)	AIT (° C)
	L_{25}	U_{25}		
Carbon monoxide	12.5	74	–	–
Chlorobenzene	1.4	–	21	640
m-Cresol	[8]1.1	–	–	–
Crotonaldehyde	2.1	[14]16	–	–
Cumene	[1].88	[1]6.5	–	425
Cyanogen	6.6	–	–	–
Cycloheptane	1.1	6.7	–	–
Cyclohexane	1.3	7.8	–	245
Cyclohexanol	[4]1.2	–	–	300
Cyclohexene	[1]1.2	–	–	–
Cyclohexyl acetate	[4]1.0	–	–	335
Cyclopropane	2.4	10.4	–	500
Cymene	[1].85	[1]6.5	–	435
Decaborane	.2	–	–	–
Decalin	[1].74	[1]4.9	57	250
n-Decane	[12].75	[12]5.6	46	210
Deuterium	4.9	75	–	–
Diborane	.8	88	–	–
Diesel fuel (60 cetane)	–	–	–	225
Diethyl amine	1.8	10	–	–
Diethyl aneline	[4].8	–	80	630
1,4-Diethyl benzene	[1].8	–	–	430
Diethyl cyclohexane	.75	–	–	240
Diethyl ether	1.9	36	–	160
3,3-Diethyl pentane	[1].7	–	–	290
Diethyl ketone	1.6	–	–	450
Diisobutyl carbinol	[1].82	[10]6.1	–	–
Diisobutyl ketone	[1].79	[1]6.2	–	–
2-4, Diisocyanate	–	–	120	–
Diisopropyl ether	1.4	7.9	–	–
Dimethyl amine	2.8	–	–	400
2,2-Dimethyl butane	1.2	7.0	–	–
2,3-Dimethyl butane	1.2	7.0	–	–
Dimethyl decalin	[1].69	[9]5.3	–	235
Dimethyl dichlorosilane	3.4	–	–	–
Dimethyl ether	3.4	27	–	350
n,n-Dimethyl formamide	[1]1.8	[1]14	57	435
2,3-Dimethyl pentane	1.1	6.8	–	335
2,2-Dimethyl propane	1.4	7.5	–	450
Dimethyl sulfide	2.2	20	–	205
Dimethyl sulfoxide	–	–	84	–
Dioxane	2.0	22	–	265
Dipentene	[5].75	[5]6.1	45	237
Diphenylamine	[4].7	–	–	635
Diphenyl ether	[4]0.8	–	–	620
Diphenyl methane	[4].7	–	–	485
Divinyl ether	1.7	27	–	–
n-Dodecane	[4].60	–	74	205
Ethane	3.0	12.4	–130	515
Ethyl acetate	2.2	11	–	–
Ethyl alcohol	3.3	[11]19	–	365
Ethyl amine	3.5	–	–	385
Ethyl benzene	[1]1.0	[1]6.7	–	430
Ethyl chloride	3.8	–	–	–
Ethyl cyclobutane	1.2	7.7	–	210
Ethyl cyclohexane	[16]2.0	[16]6.6	–	260
Ethyl cyclopentane	1.1	6.7	–	260
Ethyl formate	2.8	16	–	455
Ethyl lactate	1.5	–	–	400
Ethyl mercaptan	2.8	18	–	300
Ethyl nitrate	4.0	–	–	–

See footnotes at end of table.

Table 37. Continued

Combustible	Limits of flammability (volume-percent) L_{25}	U_{25}	T_L (°C)	AIT (°C)
Ethyl nitrite	3.0	50	–	–
Ethyl propionate	1.8	11	–	440
Ethyl propyl ether	1.7	9	–	–
Ethylene	2.7	36	–	490
Ethyleneimine	3.6	46	–	320
Ethylene glycol	[4] 3.5	–	–	400
Ethylene oxide	3.6	100	–	–
Furfural alcohol	[18] 1.8	[18] 16	72	390
Gasoline:				
100/130	1.3	7.1	–	440
115/145	1.2	7.1	–	470
Glycerine	–	–	–	370
n-Heptane	1.05	6.7	–4	215
n-Hexadecane	[4] .43	–	126	205
n-Hexane	1.2	7.4	–26	225
n-Hexyl alcohol	[1] 1.2	–	–	–
n-Hexyl ether	[4] .6	–	–	185
Hydrazine	4.7	100	–	–
Hydrogen	4.0	75	–	400
Hydrogen cyanide	5.6	40	–	–
Hydrogen sulfide	4.0	44	–	–
Isoamyl acetate	[1] 1.1	[1] 7.0	25	360
Isoamyl alcohol	[1] 1.4	[1] 9.0	–	350
Isobutane	1.8	8.4	–81	460
Isobutyl alcohol	[1] 1.7	[1] 11	–	–
Isobutyl benzene	[1] .82	[19] 6.0	–	430
Isobutyl formate	2.0	8.9	–	–
Isobutylene	1.8	9.6	–	465
Isopentane	1.4	–	–	–
Isophorone	.84	–	–	460
Isopropylacetate	[4] 1.7	–	–	–
Isopropyl alcohol	2.2	–	–	–
Isopropyl biphenyl	[4] .6	–	–	440
Jet fuel:				
JP-4	1.3	8	–	240
JP-6	–	–	–	230
Kerosine	–	–	–	210
Methane	5.0	15.0	–187	540
Methyl acetate	3.2	16	–	–
Methyl acetylene	1.7	–	–	–
Methyl alcohol	6.7	[11] 36	–	385
Methyl amine	[4] 4.2	–	–	430
Methyl bromide	10	15	–	–
3-Methyl butene-1	1.5	9.1	–	–
Methyl butyl ketone	[5] 1.2	[1] 8.0	–	–
Methyl cellosolve	[17] 2.5	[1] 20	–	380
Methyl cellosolve acetate	[5] 1.7	–	46	–
Methyl ethyl ether	[4] 2.2	–	–	–
Methyl chloride	[4] 7	–	–	–
Methyl cyclohexane	1.1	6.7	–	250
Methyl cyclopentadiene	[1] 1.3	[1] 7.6	49	445
Methyl ethyl ketone	1.9	10	–	–
Methyl ethyl ketone peroxide	–	–	40	390
Methyl formate	5.0	23	–	465
Methyl cyclohexanol	[4] 1.0	–	–	295
Methyl isobutyl carbinol	[4] 1.2	–	40	–
Methyl isopropenyl ketone	[5] 1.8	[5] 9.0	–	–
Methyl lactate	[1] 2.2	–	–	–
α-Methyl naphthalene	[4] .8	–	–	530
2, Methyl pentane	[4] 1.2	–	–	–
Methyl propionate	2.4	13	–	–
Methyl propyl ketone	1.6	8.2	–	–
Methyl styrene	[4] 1.0	–	49	495
Methyl vinyl ether	2.6	39	–	–
Methylene chloride	–	–	–	615
Monoisopropyl bicyclohexyl	.52	[20] 4.1	124	230
2-Monoisopropyl biphenyl	[20] .53	[20] 3.2	141	435
Monomethylhydrazine	4	–	–	–
Naphthalene	[20] .88	[20] 5.9	–	526
Nicotine	[1] .75	–	–	–
Nitroethane	3.4	–	30	–
Nitromethane	7.3	–	33	–
1-Nitropropene	2.2	–	34	–
2-Nitropropene	2.5	–	27	–
n-Nonane	[21] .85	–	31	205
n-Octane	0.95	–	13	220
Paraldehyde	1.3	–	–	–
Pentaborane	.42	–	–	–
n-Pentane	1.4	7.8	–48	260
Pentamethylene glycol	–	–	–	335
Phthalic anhydride	[1] 1.2	[22] 9.2	140	570
3-Picoline	[4] 1.4	–	–	500
Pinane	[23] .74	[23] 7.2	–	–
Propadiene	2.16	–	–	–
Propane	2.1	9.5	–102	450
1,2-Propandiol	[4] 2.5	–	–	410
β-Propiolactone	[5] 2.9	–	–	–
Propionaldehyde	2.9	17	–	–
n-Propyl acetate	1.8	8	–	–
n-Propyl alcohol	[15] 2.2	[1] 14	–	440
Propyl amine	2.0	–	–	–
Propyl chloride	[4] 2.4	–	–	–
n-Propyl nitrate	[17] 1.8	[17] 100	21	175
Propylene	2.4	11	–	460
Propylene dichloride	[4] 3.1	–	–	–
Propylene glycol	[24] 2.6	–	–	–
Propylene oxide	2.8	37	–	–
Pyridine	[11] 1.8	[25] 12	–	–
Propargyl alcohol	[5] 2.4	–	–	–
Quinoline	[4] 1.0	–	–	–
Styrene	[26] 1.1	–	–	–
Sulfur	[27] 2.0	–	247	–
p-Terphenyl	[4] .96	–	–	535
n-Tetradecane	[4] .5	–	–	200
Tetrahydrofurane	2.0	–	–	–
Tetralin	[1] .84	[6] 5.0	71	385
2,2,3,3-Tetramethyl pentane	0.8	–	–	430
Tetramethylene glycol	–	–	–	390
Toluene	[1] 1.2	[1] 7.1	–	480
Trichloroethane	–	–	–	500
Trichloroethylene	[28] 12	[25] 40	30	420
Triethyl amine	1.2	8.0	–	–
Triethylene glycol	[5] .9	[28] 9.2	–	–
2,2,3-Trimethyl butane	1.0	–	–	420
Trimethyl amine	2.0	12	–	–
2,2,4-Trimethyl pentane	.95	–	–	415
Trimethylene glycol	[4] 1.7	–	–	400
Trioxane	[4] 3.2	–	–	–
Turpentine	[1] .7	–	–	–

See footnotes at end of table.

Table 37. Continued

Combustible	Limits of flammability (volume-percent) L_{25}	U_{25}	T_L (° C)	AIT (° C)
Unsymmetrical dimethylhydrazine	2.0	95	–	–
Vinyl acetate	2.6	–	–	–
Vinyl chloride	3.6	33	–	–
m-Xylene	[1] 1.1	[1] 6.4	–	530
o-Xylene	[1] 1.1	[1] 6.4	–	465
p-Xylene	[1] 1.1	[1] 6.6	–	530

Flammible limits extrapolated to 25° C at Explosives Research Center U.S. Bur. of Mines except as noted.

[1] t=100° C.
[2] t=47° C.
[3] t=75° C.
[4] Calculated.
[5] t=50° C.
[6] t=85° C.
[7] t=140° C.
[8] t=150° C.
[9] t=110° C.
[10] t=175° C.
[11] t=60° C.
[12] t=53° C.
[13] t=86° C.
[14] t=130° C.
[15] t=72° C.
[16] t=117° C.
[17] t=125° C.
[18] t=200° C.
[19] t=78° C.
[20] t=122° C.
[21] t=43° C.
[22] t=196° C.
[23] t=160° C.
[24] t=96° C.
[25] t=70° C.
[26] t=29° C.
[27] t=237° C.
[28] t=30° C.
[29] t=203° C.

Fires

There probably is no single safety item in a liquid fuels operation that receives more attention by the refiner than fire protection. Yet, as pointed out by Couch,[37] an industrial fire can be expected in this country on an average of one every four minutes. Usually the major loss to a refinery resulting from an explosion is the loss created by the ensuing fires. Many of the major losses of refineries are from fires alone. See Table 5. This table shows that of 317 chemical plant accidents studied, 38½% were fires.

Whole insurance groups have been seriously damaged financially because of losses sustained from a single extensive refinery fire. These fires often started from a very simple gas or oil leak, the result of corrosion, erosion or faulty maintenance of equipment. Each valve, each flange, each fitting of any type is a potential source of a fire in a refinery or natural gasoline plant. Of course, oil spills, storage tank roof fires, ruptured tubes in a still, loading rack fires all add to the total potential loss picture. Hydrogen is used extensively in modern refinery processes. Because hydrogen auto-ignites readily and burns with an almost colorless flame, which in daylight is virtually invisible, some companies have a painted sheet metal guard over all valves and flanges serving a hydrogen line so as to detect fires due to gas leaks. Men have been seriously burned when they have walked into an invisible fire. Sometimes equipment congestion contributes to the situation. A small fire in a widely-spaced operation might hardly do more damage than to make an entry in the company's records. In a tightly-spaced plant, a fire could be disastrous.

Modern day processes by necessity work in within chemical composition ranges that once were considered to result in certain disaster. Careful control and understanding on the part of the industry make this possible. Yet, the potential of danger remains, should anything even small go unnoticed. A study of fires is extremely important to Civil Defense for a bomb drop or sabotage action is certain to create extensive fires in storage and terminal areas.

The Whiting Fire, August 27, 1955, Figures 42 and 43, a result of a detonation, left part of a plant in shambles. The company recognizes that loss could have been reduced had there been more spacing between tanks. Fire fighting was seriously hampered.[59] But, the tank arrangement and location had operated safely for years. Plant encroachment too near to storage has occurred many places as plant capacity continues to expand in limited space, See Figure 43b.

Vapors- Most fires are from minor causes. Such was the case when vapors from a vent drifted into a source of ignition at one plant. The account of the accident is repeated here.[60]

"Nineteen fire fighters died when vapors from about 500,000 gallons of a mixture of pentane and hexane escaped suddenly from a ruptured spheroid tank in a huge ball of fire. The accident occurred at the McKee Refinery of the Shamrock Oil and Gas Corp. about 55 miles north of Amarillo and located between Dumas and Sun Ray, Texas. Rupture of the spheroid followed by about an hour the original fire alarm given at 5:45 A.M. on Sunday morning July 29, 1956.

"Flame impingement from burning vapors issuing from a vent on the spheroid weakened the metal on the top plate above the tank vapor space, and this was responsible for the violent rupture of the tank. The lives were snuffed out by the heat wave resulting from the bulk release and ignition of the flammable vapors, and over 30 other people, many spectators, were burned although some were standing 1,200 feet away when the spheroid failed.... See Figure 44.

"The fire was seen to originate at an open-fired heater within the diked area of an asphalt tank approximately 350 feet downhill from the spheroid. A very light south-west wind was blowing towards the asphalt tank. The fire apparently flashed back through the vapor cloud to the spheroid. For the next hour the tank was involved in both a ground fire involving a liquid spill from a possible live leak in the vicinity of the tank's pump and a fire at the gauging device and vents....

"An indication of the intense heat generated by the tank rupture can be judged by the paint which blistered on company houses 3,000 feet away and by the post-fire condition on the leaves of trees as far as a mile away.

"The flaming ball of vapors released by the tank rupture resulted in the ignition of one 20,000 barrel diesel oil tank 200 feet away (containing 6,500 barrels of diesel oil) and two 10,000 barrel tanks of crude oil (containing 6,000 to 8,000 barrels in one and 2,000 barrels in the other). These crude oil tanks were 450 feet and 550 feet from the ruptured tank. Why these tanks, which were new cone roofed tanks equipped with flame arresters on the vents, caught

59 Woodworth, Miles E. "Whiting Refinery Fire" National Fire Protection Association Quarterly- October 1955

60 Woodworth, Miles E. "Texas Refinery Tragedy" Report by National Fire Protection Association- Reprint Q 50-3 from October 1956 NFPA Quarterly-

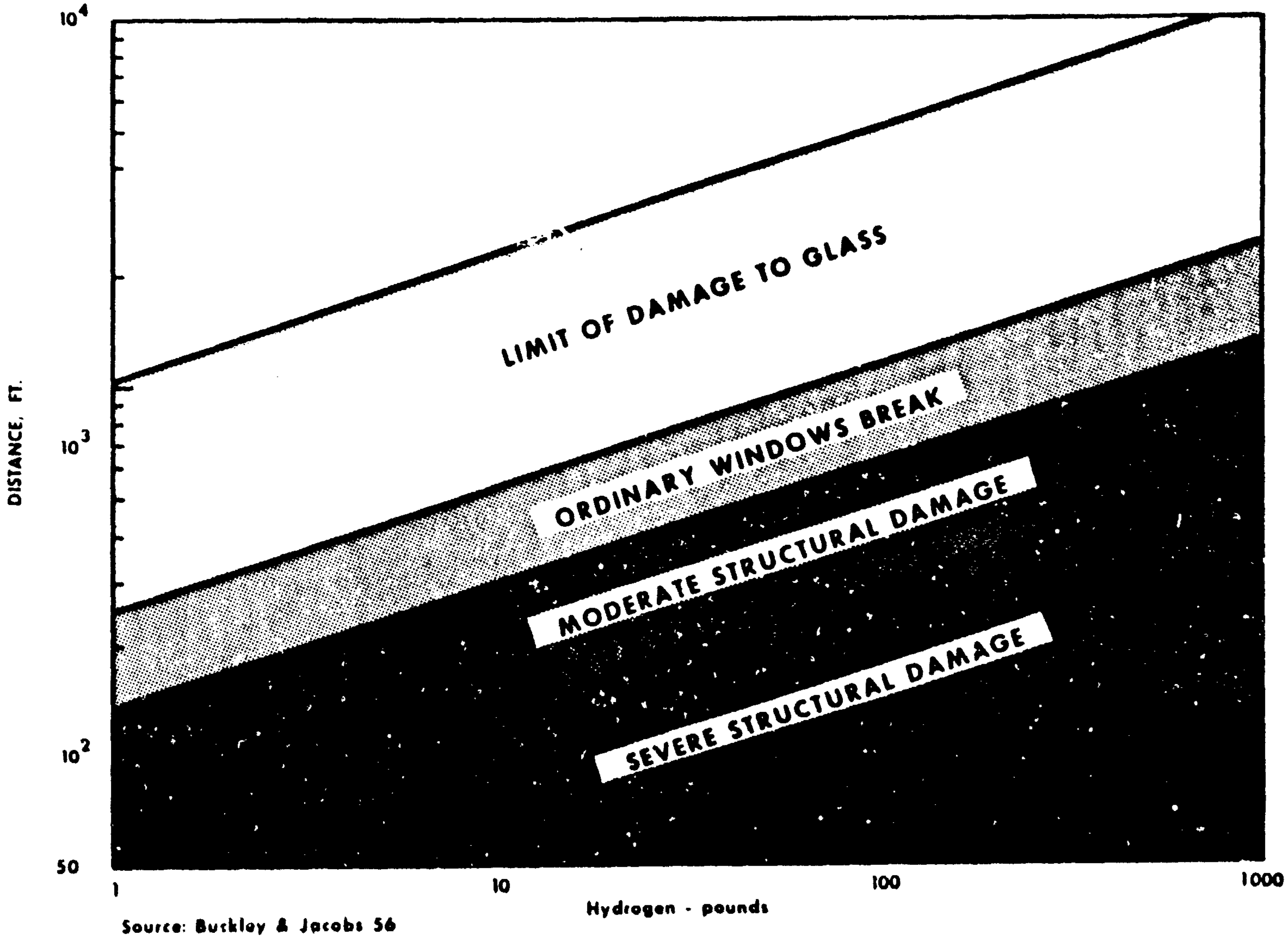


Figure 41. Potential Danger from the Release of Free Hydrogen

(Source: Buckley & Jacobs 56)

Table 38. Proposed Quantity-Distance Tables for Liquid Hydrogen

(A) Distance to inhabited buildings Pounds Over	Not over	Distance (feet)	(B) Distance between storage tanks Pounds Over	Not over	Distance (feet)
0	200	100	0	2,000	50
200	1,000	150	2,000	10,000	100
1,000	5,000	200	10,000	20,000	150
5,000	20,000	250	20,000	40,000	200
20,000	40,000	300	40,000	60,000	250
40,000	100,000	350	60,000	100,000	300

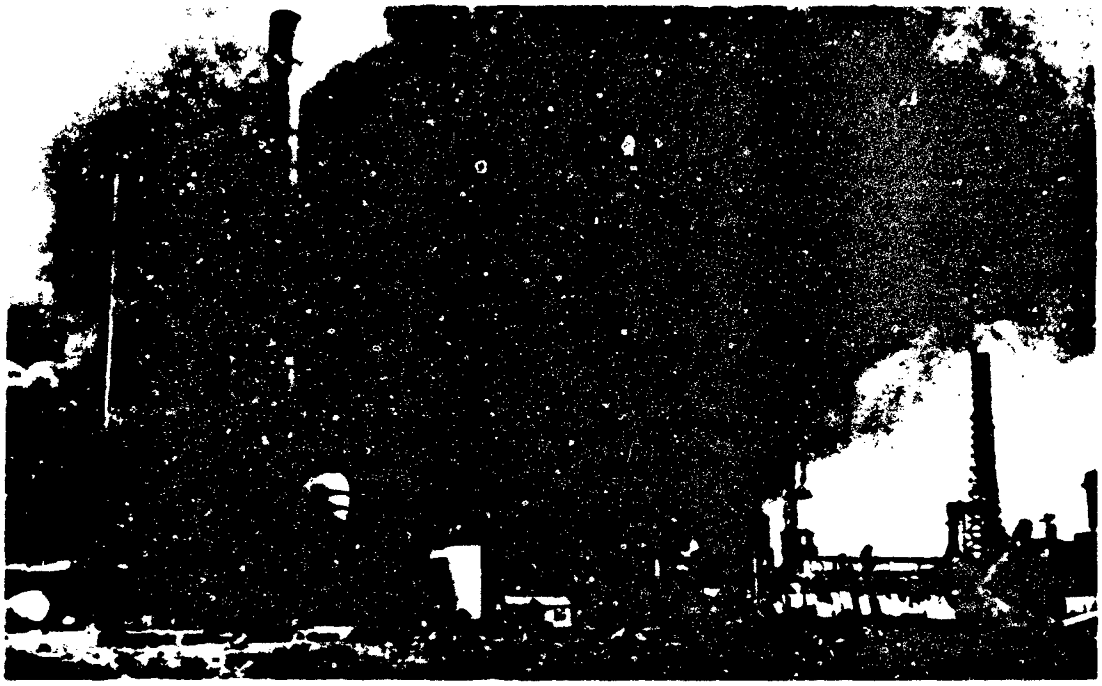


Figure 42. Fire Boils up Dark Smoke Behind Wrecked Cracking Plant.

Little more than a tangle of pipes and tanks remains where formerly stood the 26-story hydroformer cracking tower.

fire is one of the minor mysteries of the fire, particularly since other tanks much closer were not ignited and remained relatively undamaged. Also ignited by the fire blast was a railroad trestle approximately 1,250 feet away and two bulldozers were destroyed by fire in the tank farm 1,200 feet away.

"The fires burned out the next day and the refinery was back in operation on the day following the fire. Of the top three management personnel of the refinery, two were hospitalized and one was killed. Top officials of the company came from the home office to keep the plant running."

The conclusions reached by Mr. Woodworth are as follows: "This is another case which condemns the widely accepted practice of locating tank vents on pressure tanks in such a manner as to permit flame impingement on a tank's vapor space. (See July 1954 Quarterly and NFPA Reprint Q48-1 (25 cents) and Flammable Liquid Fire Loss Bulletin Series 1956-1 (35 cents).

"The installation of a fixed water spray system on all pressure storage tanks would eliminate most of the hazard of a tank rupture by keeping the metal in the tank cool. (See the Standards for Water Spray Systems for Fire Protec-

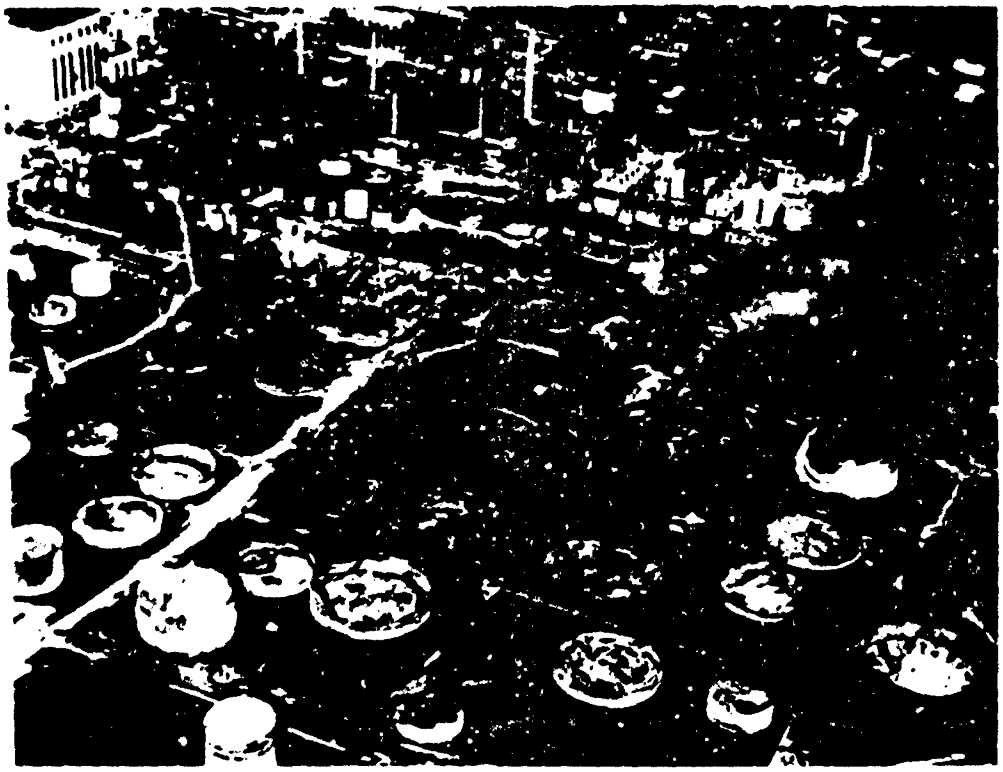


Figure 43. These 'Pies' are Well Baked. - A refinery, rocked by blasts and fires.

tion, NFPA No. 15). Fixed water spray systems assure a flow of the important cooling over the tank shell which cannot be achieved in any other manner.

"Where necessary to fight fires involving any type of pressure tank, the fire fighters should recognize the possibility of a tank rupture and, therefore, the necessity of applying cooling water streams on the tank. If for any reason it is impossible to apply cooling water streams on the tank shell, fire experiences in this type of rupture would indicate that all personnel should be removed from an area at least 1,000 feet from the tank and even at this distance, all personnel should be protected.

"The location of direct-fired heaters downhill from volatile flammable liquid storage tanks places a source of ignition within the possible path of vapor travel.

"Cast iron should not be permitted in any flammable liquid piping, valves or connections.

"Several refineries feel it is safer practice to locate pumps outside of a diked area where they would not be subject to fire exposure.

"The installation of adequate fire mains in tank farm areas in refineries has proven its value for necessary fire fighting operations.

"Finally, all companies and fire departments should renew their fire fighting procedures for fighting pressure storage tank fires. It is hoped that the tragic lessons of this fire will prevent future tragedies of this nature."

The literature contains numerous references to various causes of refinery fires. Many involve flash back type of fires where vapors from a vent has found an ignition source. There are cases of record where lightning has ignited vented gas. Static electricity generated by the rapid and turbulent flow of liquids is frequently indicated as the heat source responsible for an ignition. Each refinery fire account is interesting and educational for such exposes potentially weak or vulnerable areas in an installation. In time of war, a knowledgeable saboteur certainly would use the weaknesses to create "accidents". Everyone in the plant has the responsibility to be alert for the possible sources of trouble and either correct the situation or report it in writing to some responsible person.

Only recently the failure of corroded bolts on the bonnet of a valve appears to be the focus of the cause of a multimillion dollar refinery fire.

The Fire Journal of May 1968 gives this account of a major refinery fire.[61] See Figure 45.

61 Fire Journal "Oil Refinery" News Article, May 1968, page 8

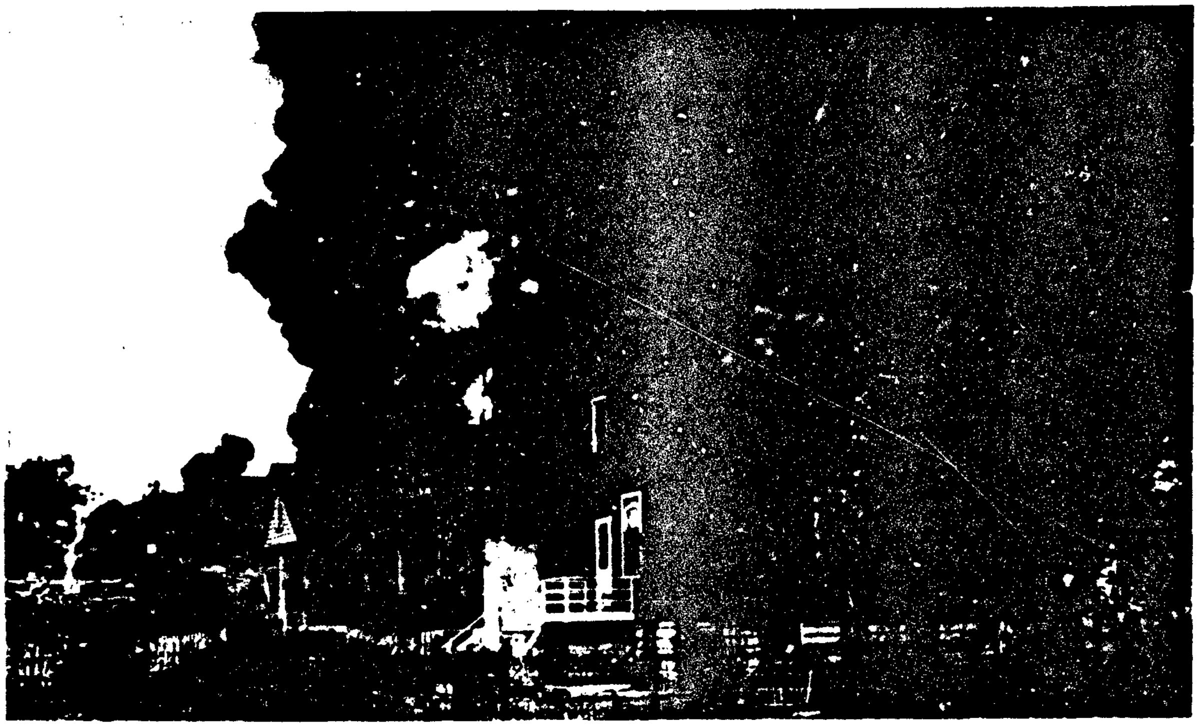


Figure 43 b. This row of homes were evacuated as fire in the huge plant menaced them. A fireball from exploding storage tank can be seen amid column of black smoke. Encroachment of a refinery by the community often increases risks.

"At the Cities Service Refinery in Lake Charles, Louisiana, a 10-inch isobutane underground pipeline ran to an alkylation unit from two remote spherical tanks. The line operated under 50-psi design pressure. A valve in the line was in an open pit which was filled with water from recent rains. The bolts in the bonnet of the valve had badly corroded because of vapors from a leaky sulfuric acid line that ran underground near by. On August 8, workmen saw bubbles in the water that covered the valve in the pit and realized that the valve was leaking. They proceeded to clear the isobutane line by flushing water at 110 psi through it from the alkylation unit to Sphere No. 1. See the diagram Figure 44. When a workman had determined that the isobutane had been flushed from the line and that the line was filled with water, he closed the valve to Sphere No. 1 and started to open the valve at Sphere No. 2. The 110-psi water pressure against the closed valve at Sphere No. 1 caused the bonnet to fly off the weakened valve in the pit and a geyser of water to rise into the air. When the workman saw the geyser, he thought he had done something wrong and reversed his procedure, closing the valve at Sphere No. 2 and reopening Sphere No. 1. When he did this, the isobutane back-pressured from Sphere No. 1 and discharged from the damaged valve in the pit. An estimated 500 barrels of isobutane escaped to ignite explosively, killing seven workmen and starting a fire that burned for two weeks, until the fuel had been consumed. The property damage amounted to $20,500,000 (or more)."

Froths and Spills- Few safety meetings pass without mention of a violent oil froth wave that spilled down a hill, ignited and destroyed all in its path, of a 33-acre Hancock Oil Co. refinery in Signal Hill, California. Twenty-seven acres of it were covered by the fire. Thirteen of approximately 40 tanks suffered extensive damage or total destruction. There were deaths and injuries; frothing and overflow occurred when hot oil reportedly was pumped into a tank containing water. The steam-oil combination created a burnable soapsuds-like froth that spread rapidly downhill throughout the plant. See Figure 46. The reported damage was in excess of $9,000,000. For the full story one should read the original account by Woodworth,[62] a part of which is reviewed here to point out vulnerable spots that failed in the plant on this occasion - conditions that still exist in other plants of the country.

"The refinery is located on ground with a 2.3 percent slope from 90 foot elevation at the south side (near the tank that frothed over) to 60 feet at the north boundary. The ground slope from west to east was from 0.5 to 1 percent.

62 Woodworth, Miles E. "Oil Froth Fire at Signal Hill Refinery" Reprint Q 52-5, October 1958, NFPA Quarterly

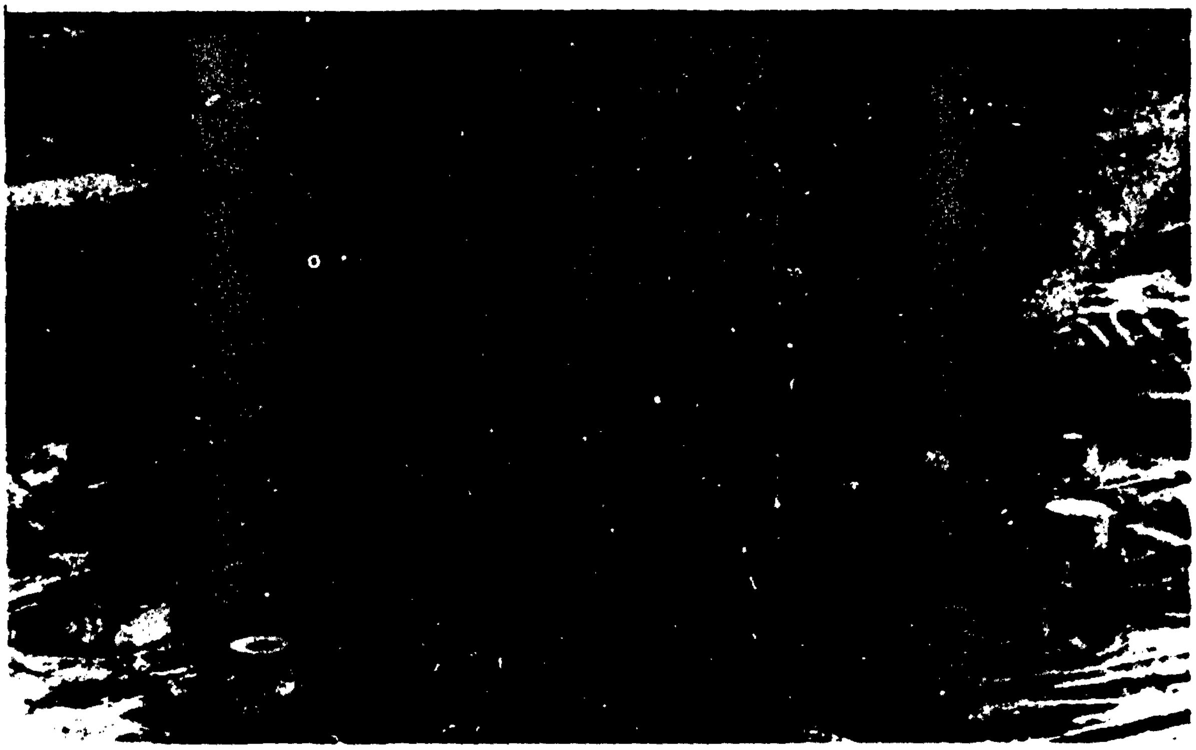


Figure 44. Aerial view shows the variety of tanks in the tank farm of a refinery near Amarillo, Texas. The diesel and crude oil tanks (ignited following the rupture of a spheroid at "A") are still burning. In the right center (at "B") is the companion spheroid to the one destroyed.

Source: National Fire Protection Assn Photo

The riveted tanks of 2,000- to 80,000-barrel capacity were on the south and east sides...."

"The initial tank involved (No. 65) was in the southwest corner of a group of six 80,000-barrel tanks, one 30,000-barrel tank, and nine smaller tanks. The diked areas, in general, were capable of retaining 75 to 100 percent of the capacity of the tank or tanks contained therein. The larger tanks were individually diked.

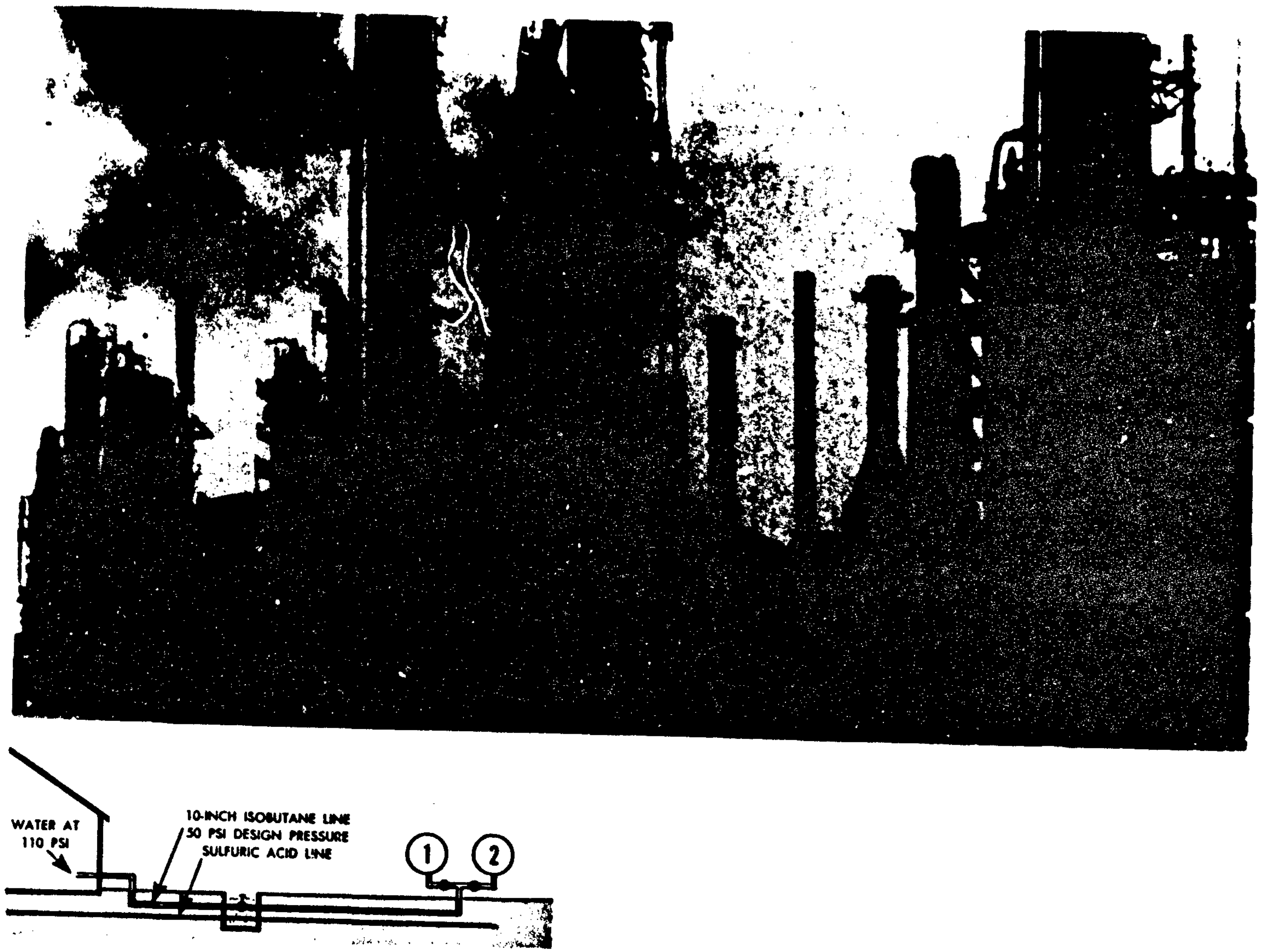
"The straight-run unit fractionating tower supplied hot residual bottoms (150-200 Saybolt seconds Furol at 122° F.) to the adjacent thermal catalytic cracking unit. A part of this stream was diverted to the uninsulated 80,000-barrel cone roof tank (No. 65) in order to maintain a temperature in the tank of about 300° F. The tank was located about 600 feet south of the fractionating tower. The temperature in the tank on the morning of the fire was 315° F. This tank served as a feed tank for the viscosity breaker and the thermal catalytic cracking units. Gas oils from other locations in the refinery also were pumped occasionally to tank No. 65 after being heated. An overshot fill line to deliver product inside the tank terminated about four feet from the bottom of the tank. There were no steam coils in the tank.

"At about 1:45 P.M. on May 22nd a rumbling noise was heard issuing from tank No. 65 and steam was seen blowing from the steam vents. About 30 seconds later violent frothing tore a section of the roof from the shell of the tank on the north half (refinery side). The froth expelled from the tank, filled the diked area and flowed over a considerable area without igniting. In a warehouse on adjacent property, about 300 feet to the west, this wave of froth was three-and-one-half feet deep. Following this first eruption, the tank remained quiet for a time although there was steam coming from the froth in the diked areas around tank No. 65 and an adjacent tank.

"About eight to ten minutes after the first frothing there was a tremendous second eruption of oil froth from the tank. This wave of oil froth was ignited by one of the many sources of ignition in its path. The burning froth swept through the refinery to the north taking approximately five minutes to travel 2,000 feet. The burning froth was one and one-half to two feet deep as it entered a storm drain at a street intersection 2,000 feet from the tank of origin. Fire was observed issuing from manhole covers from this storm drain at a distance of 2,000 feet from the point of entry.

"The wave of burning oil froth swept through approximately 70 percent of the processing and fractionating facility area. One man was caught in the wave of burning oil froth in the parking lot and another man at the opposite end of the refinery near the oil separator pump.

"Burning oil spread so rapidly through the process area that reportedly no depressuring or emergency shutdown procedures could be taken. Since there was some failure of pipe



Source: *Fire Journal May 1968*

Figure 45. A Corroded Valve Causes a Refinery Fire

Figure 46. Refinery Fire Signal Hill, Calif. This view probably was taken about five minutes after the outbreak of the fire. The burning froth wave has just reached the 500,000 cubic foot gas tanks at "A" and as yet has not reached Spring Street ("B"). The arrow points to one edge of the first froth wave which did not ignite.

Source: N.F.P.A.

supports and piping due to the intense fire, it is presumed that depressuring of the units was accomplished through broken piping. In the process areas subject to direct fire, piping, instruments and wiring were destroyed but major structures escaped serious damage. Severe fires were created in the processing area from the pipe line failures and depressuring of units through these breaks.

"Winthin two hours the fire was extinguished or had burned all the fuel in all areas except for the fires in the tank farm section of the plant and a few spot fires. It was 40 hours later before the last tank fire burned out. In those areas where only the oil froth supplied the fuel, the fire was controlled within 30 minutes."

Woodworth continues, "Unprotected steel supports for various vessels and unprotected pipe supports failed as could be anticipated, whereas, in the same fire areas, supports that were insulated or fireproofed remained comparatively undamaged. Insulation that was iron wire tied seemed to withstand the fire well but metallic binder straps failed.

"Four 500,000 cubic feet horizontal gas storage tanks were on the adjacent downhill side of the refinery belonging to the City of Long Beach Gas Company. These tanks were supported on unprotected steel columns which failed at one end of the tanks permitting the tanks to drop a short distance to the ground. Fortunately, these tanks were practically empty.

"All welded steel piping with provisions for expansion withstood the fire effects. On the other hand, large screwed pipe couplings and screwed valves failed quite generally.

"Electrical and instrument tubing was totally destroyed within the fire area.

"The vulnerability of control rooms to exposure fires has long been ignored in refinery design. Even though wired glass windows were used in the thermal catalytic cracking control house, the wired glass was not sufficient to protect the contents and the wired glass melted. The control house instruments were completely destroyed.

"The design and layout of the plant's fire main made it unusable for a time during the fire. Brass fittings melted out making the system inoperable until they were replaced. Those hydrants located in or near drainage ditches were not accessible during the initial fire.

"The location of adequate curbs and drainage ditches is important. In this fire, curbs in some areas restricted the fire damage.

"Corrugated asbestos board, used as protection for the elevator on the thermal catalytic cracking unit, was destroyed to a height of approximately 30 feet."

In summary and pointing out lessons learned from this accident, Woodworth calls these points to our attention.

"1. The use of an 80,000-barrel tank for the storage of hot oil feed stock is undesirable.

2. The many lessons learned in other flammable liquid processing plant fires which were duplicated in this refinery fire are:

a. Piping: The ability of all welded pipe to withstand fire exposures particularly when designed for expansion. The failure of cast iron fittings and valves, large screwed piping and connections, and melting of brass fittings can be expected during fire exposure.

b. Drainage Ditches: Open drainage ditches must be considered as a severe fire exposure hazard due to the possibility of burning oil flowing in the ditch. Characteristically, large fires have imposed water runoff and disposal rates in the order of 10,000 to 20,000 gallons per minute.

c. Control house: Control houses are susceptible to severe fire loss. Any facility of the importance and value of a control house located in areas of potential fire exposure should incorporate the maximum protection commensurate with the importance of those facilities. They should not face toward processing areas and should be built of reinforced concrete.

d. Curbings: Curbings around certain process areas not only may keep burning liquid out of an area but also may confine small spills to the curbed area.

e. Emergency Vents: All flammable liquid storage tanks should be equipped with properly-sized emergency vents except weak seamed cone roofed tanks. The weak seamed cone roof serves as an emergency vent.

f. Diked Area Drains: Due to the high water rates frequently used for cooling exposed tanks, adequate drains with proper valving would provide fire fighters with a means of draining water and not oil from the diked area. Such drains have proven most effective in preventing spread of burning oil on the surface of the water as well as enabling firemen to extinguish small spill fires safely.

g. Structural Steel: Fireproofing of structural steel members or automatic fixed water spray protection have proven to be effective protection. All unprotected steel supports can be expected to fail shortly after being exposed to fire.

h. Communication: In large area fires radio communication is necessary. Mutual aid involving fire departments on different wave lengths handicaps the control operations.

i. Foam Application: If it is desired to extinguish a fire in a diked area, the foam application rates called for in the Standards for Foam Extinguishing Systems (NFPA No. 11) should be followed.

3. Engineering design should preclude as far as practicable the accidental mixing of hot oil and water.

4. Violent frothing by mixing hot oil and water is a well-recognized hazard with a well-proven fire and explosion record. However, this is the largest froth wave from this cause known to the NFPA. The quantity of oil involved was exceptionally large.

5. Approximately 50 percent of the $9,000,000 loss was from smoke and fire damage to property outside the refinery. However, this loss figure does not include the loss from business interruption nor the many indirect losses due to lack of production."

Frothing occurs when hot oil is suddenly mixed with water in the bottom of a tank. It also occurs when hot heavy oil was put into a tank that still contained volatile low boiling liquids. Frothing and boil-over is a common occurrence when a fire engulfs a tank containing a petroleum product. Even fire foam sprayed into a tank of hot oil can encourage frothing and further trouble under some conditions.

A recent accident that caused great loss was similar but still dramatically different than the frothing case discussed. This fire occurred at the Shell Nederlands Refinery in Pernis,

The Netherlands. Frothing occurred when a hot oil and water emulsion in the bottom of the tank separated or broke causing separation of the water and oil. The separated hot oil reacted with volatile portions of the cold slop oil above it causing a violent vapor release and boil-over. The account of the accident is reviewed here.[63]

"Shortly before 4:30 A.M. on January 20, 1968, a terrific explosion rocked the Shell Nederlands Refinery in Pernis, The Netherlands, and the surrounding residential towns. Two refinery employees perished, and 75 to 85 employees and area residents received injuries. Buildings, refinery equipment, and storage tanks were destroyed on about 30 acres of the approximately 220-acre plant. The estimates of damage run to about $28,000,000 to the plant, with additional losses to other property. In the nearby community of Hoogvliet about 200 tons of broken window glass were removed and glaziers replaced about 12,000 square yards of glass. Flying glass did considerable damage to home furnishings, and many people suffered injury from the glass. Reportedly, windows were broken as far as 9½ miles away.

"Everything seemed to be normal at the refinery until about 4:15 A.M. when employees noticed that a slop oil tank was overflowing. Within a few minutes a cloud of hydrocarbon vapors had erupted from the tank. The cloud did not disperse, because of the calm air, but spread over a radius of 100 to 150 yards in an area that included oil-heating furnaces and other sources of ignition. One or two minor explosions occurred almost simultaneously, closely followed by a major explosion having the characteristics of a detonation, which caused extensive damage and numerous fires.

"How the open-air explosion developed such force is not fully understood. As far as is known, such an incident involving flammable liquids has never occurred before. In fact, open-air explosions of gas-air mixtures have been rare. The vast dimensions of the cloud could have been an essential factor. Furthermore, the hydrocarbon-air mixture must have been within the explosive limits throughout the cloud. One possible explanation of the extreme violence of the explosion is that the cloud may have consisted of a mist-vapor-air mixture.

"The 30-acre part of the refinery that was destroyed was divided into seven blocks of varying sizes surrounded by roadways. The first block comprised two paraffin-refining units, both operating at the time. The second block contained a small office building, a small transformer station, and an air compressor station to supply the instruments. The third block (in which the explosion occurred) contained a cracking unit for the production of coke, a pumping installation in a brick building, a number of fractionating columns, and seven furnaces to heat oil. The fourth block held a transformer station and the central office, the fifth a sulfur-extracting plant, the sixth a tank farm of 18 small tanks, and the seventh the so-called 'oil catchers', or waste oil-separating pits.

"In addition to buildings and equipment, the explosion destroyed about two dozen tanks in the seven-block area and damaged more than 100 tanks in other areas of the plant. The explosion also destroyed the water-spray systems and the foam piping on tanks so protected. As a result, the fire spread freely and very fast during its first minutes." See Figures 47 and 48.

"The first engine arrived at the fire at 4:35 a.m. Although the well-equipped plant fire brigade had been activated, it was delayed because the overhead doors of the fire brigade garage, which had been damaged in the explosion, had to be lifted by two fork lift trucks.

"The mass of fire and the heavy smoke made it difficult for the firemen to appraise the situation. Knowing it would be useless to spread fire-fighting apparatus at random over the sprawling plant, the fire officers concentrated the forces near the main entrance to the refinery. After consultations between the officers of the municipal and company fire brigades and study of a plot plan that had been obtained, it was decided to surround the fire on two sides with the main fire-fighting forces. Despite a drain on the water supplies from extensive damage to the water-spray systems, water for fire-fighting remained plentiful. The boats were also supplying water in large volume. Extremely important from the point of view of fire-fighting were the large roadways around the various installations and groups of tanks. It was not difficult to move apparatus, aside from the obstacles presented by the fire itself.

"Between 4:35 and 7: a.m. the equipment and hoses were advanced several times as various areas of fire were knocked down and extinguished. During that time the alarm chief several times reassigned and moved up fire companies in the built-up area of Rotterdam, so that the city would be adequately protected in case further fires occurred.

"After a hard fight the fire was contained to one tank farm. But just when danger seemed to have passed, without warning an explosion blew the roof off a tank and a tongue of flame and smoke shot 500 feet into the air. Flaming oil flowed over the ground, and firemen had to run for their lives.

"By about 10:00 a.m. an attempt had been made to extinguish the fire in one of the tanks with foam. However, the foam caused the viscous contents to froth over the rim of the tank, so it was decided to let the fires burn out in the three tanks that were still on fire. After those fires had burned out, most of the municipal firemen were allowed to leave the scene. Two fire engines with 12 men and the company fire brigade remained at the refinery for possible emergencies. The next day at 12:15 p.m. they reported that the fire was completely out.

"In all, some 50 members of the company fire brigade, 200 municipal firemen, and 39 members of the Municipal Harbor Service fought the fire. Together they had unrolled some seven and a half miles of hose. The company fire brigade used over 3,700 gallons of foaming agent, which several suppliers replenished during the fire. The plant and municipal stocks of foaming agent were ample at all times.

"The slop tank was full of a variety of liquids from several sources, some of which were volatile liquids with low boiling points. The tank was heated by low-pressure steam coils in the bottom. At the time of the incident the coils were covered with water that had settled out of the oil. On

63 National Brandpreventie Instituut "Shell Refinery Fire- The Netherlands" as reported by Miles E. Woodworth, Fire Journal, Sept. 1968, p. 110

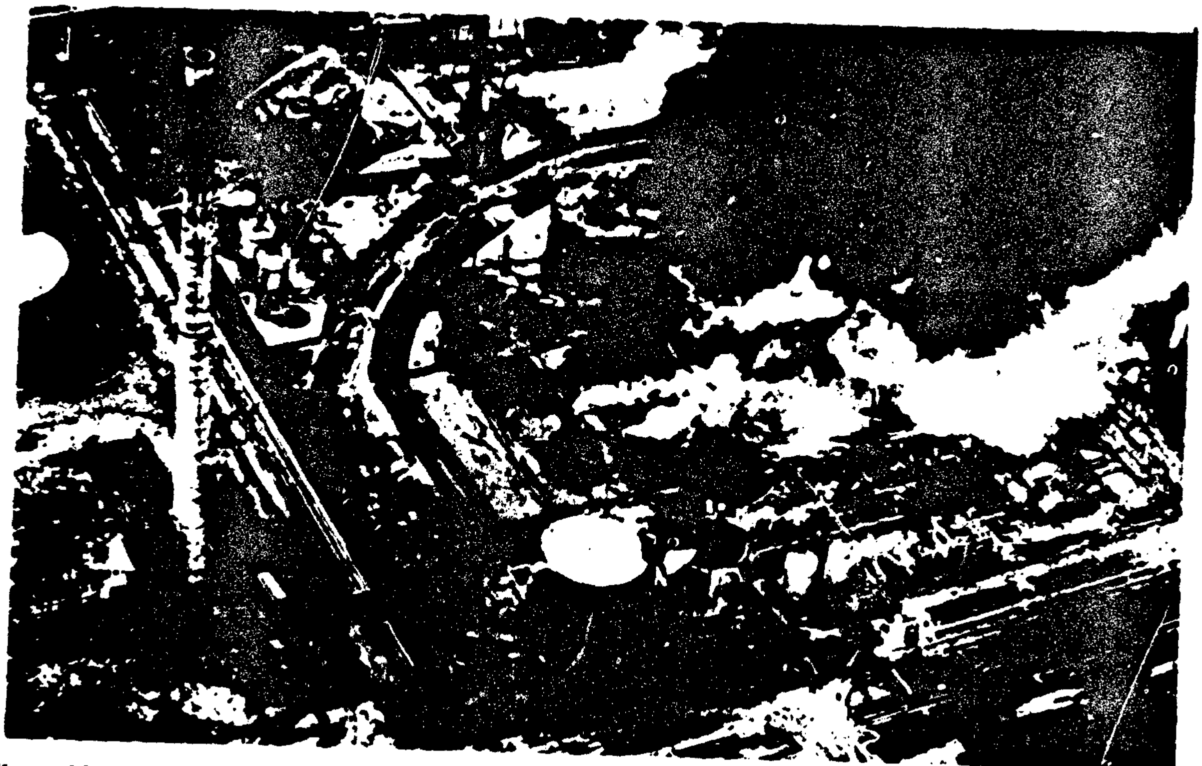


Figure 47. An Aerial Photo Showing the Center Area of the Plant, where the Explosion Occurred, Followed by Almost Complete Destruction.

Shell Nederlands Refinery in Pernis, The Netherlands
(Source: D. Lemcke)

top of the water bottom was an approximately three-foot-deep layer of a stable water-in-oil emulsion. The remainder of the tank contained emulsified slop oil.

"When there is a considerable difference in temperature between layers there will be marked differences in temperature at the interface. When the layer of stable emulsion reaches its breakpoint at a certain temperature, the oil and water separate, each maintaining the same temperature as the original mixture. Subsequent laboratory tests indicate that the following sequence of events took place in the tank: When the emulsion broke, the hot oil mixed with cooler slop oil. The sudden transfer of heat caused boiling of the volatile components of the slop oil, with a resulting slop-over of the tank contents as the vapors went up through the liquid in the tank. Once boiling started near the broken interface, it increased in violence as the hydrostatic pressure near the bottom of the tank was lowered. The vents were unable to handle the resulting strong frothing action, the tank roof failed at the weak roof-to-shell seam, and the contents started to flow out of the tank.

"Several cases have been reported in which hot oil has suddenly mixed with water in the bottom of the tank, causing the water to boil and resulting in a violent frothing action that has expelled the contents of the tank. There have been several cases in which violent frothing action occurred when a hot heavy oil was put into a tank that still contained volatile, low-boiling liquids. However, the Netherlands case is the first to be reported to the NFPA in which the reverse happened; i.e., frothing in a tank containing hot oil and water at the bottom and cold oil on top. Nevertheless, the results were the same, with frothing action caused by vapors forcing up through a viscous liquid."

Since a number of refinery fires relate to slope tank spill-overs or frothing, it seems important that close attention be given this potential danger. Keeping the water level at a minimum level should be a good place to start. In other cases, great temperature differences between layers within the tank should be avoided. It would appear possible to locate such tanks so that a spill would cause no trouble.

Fires are well understood. The question asked in Figure 40- is the Air-Vapor-Heat fire triangle obsolete- has the clear and simple answer of *No!* If any one leg of the triangle is removed, the fire stops. Or conversely, fires can exist only when all three portions of the triangle occur together. Fire prevention or control rely on this basic concept. In a refinery it is so easy to create ideal fire conditions, for all "elements" are always present somewhere in the refinery, petrochemical or natural gasoline plant. That is the character

Figure 48. Some of the Severe Explosion Damage to the Refinery Buildings and Apparatus.

Shell Nederlands Refinery Fire, The Netherlands
(Source: Simon H. Deboer)

of the operation. Should these three "culprits" get together, most plants are ready for action. See Figure 49. The Atlantic Richfield Wilmington, California, fire equipment is but one good example of such preparations. Each unit of the plant is protected by large monitors (permanently installed large fire nozzles) located at strategic positions so as to fog or cover with foam equipment any potential sources of a fire. Truck-mounted equipment augments the sprinkler and nozzles mounted near each unit.

The Transcontinental Cryogenic gas storage project near Carlstadt, New Jersey, has a system of remotely operated fire monitors which can direct fog or foam into equipment several hundred feet away from the operators standing at a control console. See Figure 50. By use of a closed circuit TV well protected from heat damage and a remote control system, it could be possible to fight a fire from a well protected control house without one going near the fire area.

Each company will have its own fire organization designed to meet its particular needs. The size, location and efficiency of nearby civic units have much to do with company planning. In case of a national disaster, each plant should expect to be on its own. The Hazard Survey of the Chemical and Allied Industries cited above offers suggestions concerning a fire prevention organization.[4]

"Many plants require well equipped, full-time, fire brigades. These fire brigades will vary in size and function. They should be well trained in handling all plant fire protection equipment. In addition, they should be familiar with the types of fires that can be anticipated as a result of the materials handled. Guides to the formation and training of this group can be found in NFPA Standard No. 27 - "Private Fire Brigades". Cooperative mutual-aid industrial firefighting groups can also be formed where the emergency facilities of all plants in an area are pooled.

"Fire fighting techniques may vary from one plant to another. Fires in chemical process units involving flammable liquids and gases are frequently controlled by removal of fuel from the area. This requires adequate valving, vapor relief and liquid blowdown and pump-out systems. Process steam can also be used to control some fires. Operators of process units should develop fire control techniques through "simulated emergency" training. In some cases, extinguishing a fire without shutting down fuel lines can lead to an explosion."

Full protection of critical and highly vulnerable areas in a plant is essential to avoid serious losses and to permit a minimum of interruptions to operations. Extra care or perhaps some "over protection" as compared to normal consideration will in time usually pay off. Civil Defense needs this extra plus efficiency to meet its possible needs in time of war.

Fire Storms- Much study and research is being given this subject by Civil Defense. The results of these studies sound

Figure 49. A Part of the Atlantic-Richfield Refinery Fire Fighting Equipment.
Source: Atlantic Richfield

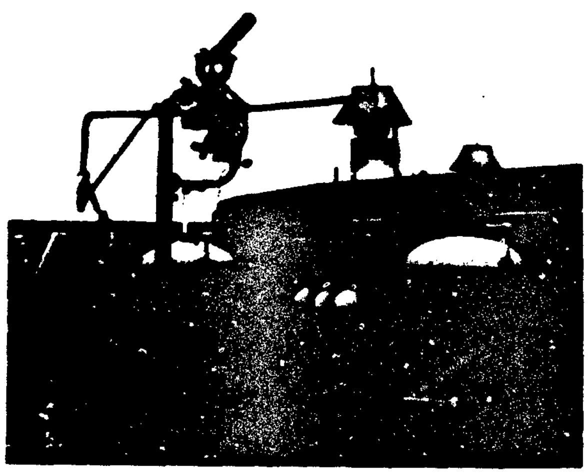


Figure 50a. A Remotely Controlled Foam-Fire System.
Source: Transcontinental Pipe Line Co. (Stephens)

Figure 50b. Close-Up View of Remotely Operated "Monitor" Equipped to deliver Fog or Foam.

Source: Transcontinental Pipe Line Co. (Stephens)

great warnings for peace time applications. A small refinery fire could be the source of a major and widespread fire in a community crowding in around a petroleum installation.

A fire storm might be defined as a combination of many small fires that together create convective currents that join in a central vertical column. Air rushes in to this center and up the flame-created flue. Intensive burning, extremely high temperature, and violent indrafts of air accompany this unusual occurrence. The Bel-Air Brentwood fire in 1961 at Los Angeles, California,- the Chicago fire October 8, 1871,- the Hamburg, Germany, fire created by bombing in World War II,- the atomic attack on Hiroshima, Japan, and many forest fires of the north and west are examples of near fire storm like conflagration. These fires are so intense that hurricane-like winds are created as air is heated and rushes up the central "flue"

Fires of equal intensity could occur in a tank farm area or locally in the crowded confines of some processing unit. Each account of such fires mentions the intensity of heat which occurs, the buckling of unprotected steel supports, the melting of glass and brass, the burning of electric wire, and the destruction of wooden, brick and block type buildings.

The use of bunkers in Germany in World War II saved many lives as intense fires burned around the protective structures.[64] Whole plants were built underground as air raid protection. Some had protective bunkers.

"The heat around these buildings was more than human beings could stand. Nevertheless in no instance either in bunkers or in surface shelters did shelterees come to any harm from the heat, nor did they leave the building prematurely."

It is hoped that the space devoted to the discussion of explosion and fires will identify a potentially dangerous condition existing within the reader's plant. Most operators have not experienced such major catastrophes so could overlook some accident waiting to happen. Not only must refinery losses be kept to a minimum, for the good of the industry, but also preparation to prevent such potential losses is strengthening the plant against the ravages of nature and war.

64 Police President of Hamburg- Report by the Police President of Hamburg and local Air Protection leader of Hamburg on the large scale raids on Hamburg in July and August 1943- Experiences, Vol. I: Report Translation page 88- as reported by Office of Civil Defense, Fire Aspects of Civil Defense- TR-25 July 1968

Chapter VI
RISK ANALYSIS

Risk Evaluation - (Refining Viewpoint)

The trust of much of the discussion above is in the identification of risk and sensitive areas of a refinery operation. Where hydrocarbon, air, and heat are involved, one cannot avoid certain risks, but as processes become more complex, an ever-increasing effort is required to avoid disasters.

Starting up and shutting down are certainly problem items for the refinery operators. Air or other contamination in the system, frozen lines, too much pressure, too great a vacuum, leaks, spills, plugged lines, closed vent valves, excessive temperature, hydrogen sulphide and countless other items constantly need full attention. Constant vigil and the monitoring of all dangerous areas is essential for all employees at a refinery, and training and planning for emergencies is useful in peace and pays off handsomely in time of war.

Mr. Ducommun in summing up the Whiting disaster and concluding his account on the FHU-700 detonation says, "In my earlier days in the Engineering Inspection Department of my company, and as an operator, we guarded very carefully against getting the three sides of the triangle together. (See Figure 40). We took many precautions to eliminate all of the air from equipment before the startup so that hydrocarbons and air would not come in contact. Once the unit was on stream, only two sides of the triangle existed inside the processing equipment. This was all changed when regenerative catalytic processes such as fixed bed hydroformers and cat crackers were introduced in the early 1940's.

"Hydroforming is typical of this new era of regenerative catalytic processes. If you will stop and consider, you will find that contrary to our refining techniques, these processes now require all three elements of the fire triangle – namely, the hydrocarbon stream, the oxygen-bearing inert gas used for regeneration, and finally, adequate temperatures and conditions to cause ignition if the two gas streams are admixed in process lines. Unfortunately, these three elements are needed to successfully carry out the desired chemical reactions. In the past, before both oxygen and fuel were constituents of our processes, the conventional engineering approaches of either providing sufficient strength to contain an internal explosion, or providing a pressure-relieving device (e.g., rupture disk) with quick response and adequate capacity to avert complete failure of the vessel have been adequate.

"As a result of the disastrous explosion of FHU-700, and the engineering study following that explosion, it has been found that a concept of pressure generation not generally known in the petroleum industry can be encountered in process equipment containing the right ingredients.

"It was quite well known that detonation was possible with hydrogen or acetylene or with carbon monoxide gases under proper conditions in vessels or lines, regardless of size. The FHU-700 explosion further revealed the heretofore little realized fact that detonation can occur in large vessels with hydrocarbon gases – resulting in fragmentation of a vessel constructed of alloy steel, two-and-one-half inches thick, and hurling a 60-ton piece through the air a distance of 1,200 feet!

"Detonation involves the development of violent shock waves. Consequently, engineers must have a knowledge of both limits of explosibility and critical vessel dimensions. We know now that the pressure which may be generated in critically sized vessels as a result of detonation are many times that previously anticipated. Likewise, in dealing with hydrogen, which predominates the gases in catalytic units, we can now have dangerous mixtures of process-gas and air over a range of 1 to 75 percent gas; whereas with hydrocarbons alone, which we dealt with in older processes, we encountered explosive mixtures in concentrations of 1 to 8 percent. Thus our potential explosive range has increased some tenfold because of the presence of hydrogen.

"Obviously, the conventional approach used in the past is not capable of doing the job since sufficient strength cannot be built into the equipment and pressure-relieving defices do not react with sufficient reliability and speed.

"The only answer to such a problem, therefore, is a realistic evaluation of hazards leading to the installation of adequate safety features, and reliable controls in a 'fool-proof' fashion to prohibit the contact of the sides of the triangle except under rigorously controlled conditions.

"It therefore behooves us to keep in mind, at all times, the hazards which may be encountered in this type of equipment. This is the reason that we must be willing – and we are willing – to spend additional money to provide the safeguards. By additional money, I do not mean hundreds of dollars, but thousands and sometimes hundreds of thousands.

"We must supply additional oxygen analyzers to assure us that we are operating at all times with a rigorously controlled oxygen supply. Inert gas holders, dependable motor-operated double block valves (with additional valves for blind equivalents), and seal-gas systems may also be used to assure a separation of the fuel and oxygen sides of the triangle at all times. Increased hazards must be recognized by providing these additional safeguards.

"What's more we have taken a good hard look and operationally appraised all of our refineries. We especially reviewed the importance and condition of fire walls. I think many refineries, if not the entire refining industry, has undergone this same self-appraisal since the Whiting fire.

"In addition to the reappraisal of equipment design which I have emphasized, a critical examination should include:

1. Reviews and any necessary revisions of operating orocedures.
2. Continued training.
3. Full use of experience gained from any operating difficulties and of experienced personnel.
4. Thorough instruction of operating personnel.

5. Full and coordinated use of the experience and technical knowledge of appropriate staff groups.

"Such practices can be effective. As evidence, remember that although we handle flammable materials we have – by diligence and training, and with the cooperation of our employees – made life safer in refineries than in homes. The refining industry has an outstanding safety record. For example, before the fire at the Whiting refinery, the disabling frequency was less than 1 disabling injury per million man-hours worked. It was actually 0.84.

"Lessons learned from our experience were also valuable in our solution of the problems of rehabilitation. The day before the fire we were running crude at a rate of a little more than 200,000 barrels per day. With the all-out effort of all of our people, we were back to approximately the pre-fire level on November 20, just 85 calendar days after the start of the fire.

"An ultraformer was constructed in 11 months and placed 'on stream' July 19, 1956. The ultraformer is on the site formerly occupied by the tank field which was burned out. Even before the fire was extinguished, the decision was made to build new tanks elsewhere. The new field, containing 14 tanks which were filled February 4 and May 15, 1956, is located in a virgin area more than a mile from the main part of the refinery."

It should not appear that the new refining processes are being indicted as being bad actors. Far it is from the case, for millions of barrels of oil are safely processed in the United States each day. It is always possible to overlook a "minor" item though and create unfortunate circumstances.

In another paper, Docommun[65] made the following statements.

"The fact is that refinery safety has, broadly speaking, three equally important aspects- and too many oilmen, even today, are paying full attention to only two of the three.

"One aspect is what we might term personnel. Here we do, almost with exception, an outstanding job. We see to it that refinery workers wear tin hats. We issue safety bulletins in a constant stream. We insist on the use of safety goggles and safety shoes. We harp constantly on the proper use of tools. We pay close, rewarding, repetitive attention to personal safety.

"A second aspect is what we might term equipment safety. And here again the industry record is admirable. We design all units with substantial safety factors. We inspect the equipment repeatedly to make sure it is safe. The Pressure Vessel Research Committee of the Welding Research Council, with the American Petroleum Institute as a contributor, devotes as annual budget of nearly a half a million dollars to reducing the possibility of vessel failures. We do a fine job on equipment safety.

"But the third aspect of refinery safety has to do with the refining process itself as such in the vital area of process safety. And here, I'm greatly afraid, we are still- as an industry- turning in something less than an adequate performance.

"Accidents in the course of processing continue to occur with a distressing frequency. And why not? In most instances because we fail to observe certain simple, obvious fundamentals . . . .

"Explosions follow the iron laws of chemistry and physics, which means that they can be- and consequently should be- avoided.

"One trouble is that most of us- or at least too many of us- let ourselves be tranquilized by past performance. A given operation has been performed in a given way for two years or ten years or even twenty years, and nothing has gone wrong so far. Therefore, we tell ourselves, nothing *will* go wrong. It doesn't follow. Not by a long, loud, destructive shot.

"For two years or ten or twenty we may all too easily have been just plain lucky. Two sides of the familiar fire triangle may have been present during all that time- fuel and air or the potentially much more dangerous commercial oxygen. We may have been getting by just because the third side of the triangle- ignition- wasn't present.

"We're playing, though, not just with fire, but with violent explosion, the super-explosion of a detonation, if we assume that the ignition will continue to be absent. Repeated, tragic experience should have convinced us long since that, particularly in a refinery, nature always stands ready to provide the ignition one sneaky way or another.

"When the ignition is provided- by a lightning bolt or a stray electrical spark or some other source- in the case of a storage tank, usually relatively little damage is done. The tank roof blows, the tank's contents flame, and that's the end of it. But when it's a pressure vessel or a line that blows, an almost literal hell breaks loose."

Ducommun continues, "Normal explosion waves travel rather slowly, at most, a few hundred feet per second. Detonation waves, on the contrary, move at supersonic speeds- from 2,000 ft. to 8,000 ft. a second in air-hydrocarbon mixtures.

"Ordinary explosions may produce pressures as much as 6 to 10 times the initial pressure in a given vessel, a destructive force in and of itself. But a detonation will produce immediate pressure as high as 60 to 100 times the initial pressure, and impact and reflection may multiply this immediate pressure by a factor of 32 or more.

"An explosion can crack even a sturdily walled vessel and render it useless by tearing it apart. But a detonation will fragment the same vessel and casually flip a 60-ton chunk of it more than a fifth of a mile through the air . . . .

"Over the past five years there have been at least twelve major detonations involving the mixture of air or oxygen and hydrocarbons in a variety of pressure systems.

"In 1957, for example, a gasoline-treating plant at the Magnolia Petroleum Company, Beaumont, Texas, refinery suffered a detonation when some unknown ignition source fired an oxygen-hydrocarbon mixture in a salt drum.

"Early in 1959 a Dubbs coking unit at the Cities Service Oil Company refinery at Ponca City, Okla., blew when a vent valve remained closed during a startup. The unit had been safety started perhaps 6,000 times over a 30-year period, but this time ram-oil vapors mixed with compressed air, and the unit detonated.

65 Ducommun, J.C. "A Pattern for Process Safety" API 40th Annual Meeting Preprint A-13, November 14, 1960

"A month later, in February 1959, a centrifugal compressor under test at the Ingersoll-Rand Company's plant at Phillipsburg, N.J., suddenly detonated after about 6 hrs. of operation. A committee's conclusion after investigation of the detonation- I quote: 'Test loops should be designed and operated to eliminate at least one of the three elements forming the combustion triangle.'

"That same month of February 1959, detonations occurred in the air piping around a high-pressure centrifugal compressor which was being operated under the direction of the compressor manufacturer in a closed loop of compressor, air cooler, and throttle valve in the course of an initial acceptance test. Light turbine oil had been introduced into the air by improper control of seal oil during transient starting conditions, both in this compressor and in the compressor used to pressurize the closed-loop test circuit. Due to the high temperatures of over 500° F. and pressure of 750 psi, there may have been oil decomposition before the explosion.

"Other detonations in 1959 included one in a 6-in. gas repressuring line at Elk Basin Pumping Station and one in a blowdown tunnel at Pratt and Whitney . . . .

"As it became obvious that major disasters caused by hydrocarbon detonations were occurring more frequently than before, however, we intensified our efforts.

"Research- our own and that of others- gave us new insights into the problem. We found conclusive proof, for example, that while a mixture of propane and air is highly hazardous, a mixture of propane and commercial oxygen is many, many times more so. The difference in the degrees of hazard is graphically illustrated by a chart of the flammability ranges of these two mixtures. See Figure 51.

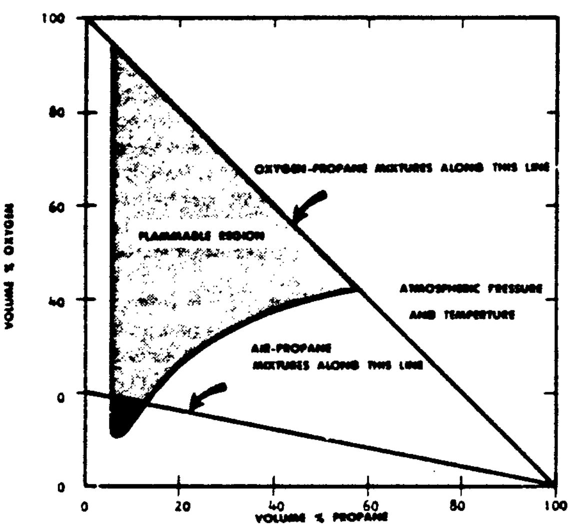


Figure 51. Flammable Limits of Propane-Air Mixtures and Propane-Oxygen Mixtures. The Larger Flammable Range for Propane-Oxygen Mixtures Indicate the Hazard of Trying to Control Such Mixtures.

"We found that, contrary to the belief of many, that size and geometry of the container do not put any practical limits on the possibilities of detonation. Blend propane and commercially pure oxygen in a container no bigger than my little finger, for instance, and you can get a detonation.

"The conclusion that flows from those two necessary assumptions is obvious: Detonations can occur in any refinery, natural gas plant, or petrochemical plant if proper precautions are not taken to prevent them. It's imperative, therefore, to take those precautions . . . .

"The problem of improving operating safety is not really complex. It yields to the same basic solution that has been successfully used in other fields of safety.

"The prerequisites are two:

1. Management- top, middle, and lower- must be so thoroughly sold on the need for safety that it can and will provide aggressive leadership and supervision. Such provision calls for use of every mangerial skill in the book.

2. All refinery personnel concerned with safety, with no exceptions, must be given a thorough understanding of the principles of process safety. It is not enough to hand them a booklet and give them a few well-worn words of advice. . . Real understanding of the problem and the ways of coping with it must be brought to and kept before everyone concerned with process safety.

"Point two of course raises an immediate question: Who are the people actually concerned? The answer is a multiple one.

"The men developing the process design are certainly involved. Their design must be such that it entails no operation that violates any of the safety principles.

"The engineers doing the mechanical design are equally involved. They must see to it that the equipment permits safe operation under both routine and emergency conditions. They have to be especially careful to provide safeguards for the critical periods of startups and shutdowns.

"The people who prepare the unit operating manuals and who train and supervise the men who turn the valves are closely involved in process safety. They have to make sure their instructions are crystal clear, and they have to be careful to provide the essential why's of operation as well as the how's.

"The stillman and his helpers aren't just involved in process safety; their very lives are staked on it. They have to know- to understand in depth- all of the how's and all of the why's, and the importance of both has to be kept constantly before them.

"Finally, the maintenance and construction people are concerned with process safety. This group, if it's kept fully informed, can act as an effective point of cross-check on all the other groups involved.

"Since each of these groups has a primary responsibility for something besides safety, the problem defines itself. It is one of establishing and maintaining a program that will insure that none of these diverse groups neglects safety under the pressure of other considerations."

In conclusion Mr. Ducommun states, "I urge each of you to examine the process safety program in your own company . . . . Make sure, in short, that process safety gets the

[illegible] and the same support as all the other phases of your continuing safety program.

"We deal in this field with potential danger to equipment costing hundreds of thousands- even millions- of dollars. More important we deal with potential danger to human life, which is worth beyond all our calculations. We cannot, in good conscience, give anything less than our very best effort to the promotion of safety."

Risk Evaluation- (Underwriters Viewpoint)

There is no group more interested in safe refinery operation than insurance underwriters. Further, it is imperative that any plant listen to these experts for few corporate managers would dare operate his company without adequate insurance. If losses become excessive, insurance rates could become prohibitive in costs.

The direct thrust of this handbook, as mentioned, repeatedly, is to stimulate the building and operating of refineries, petrochemical and natural gasoline plants capable of withstanding the rigorous conditions of either any extensive natural disaster, normal explosions, fires, or war. The national economy as well as the military basically depend on the steady flow of petroleum and its multiplicity of products. It is hoped that as new plants are built to meet the soaring demands for fuels and petrochemicals that extra strength and extra safety precautions will be built into the various units. In doing so, a company can save great sums of money in the over-all picture if for no other reason than having a safer and less hazardous operation, a more insurable risk.

A discussion of refinery risks by Robinson[66] of the Oil Insurance Association summarizes much that has been reviewed in the preceding pages and adds the underwriter's point of view.

". . . .The point is that while great strides have been made in safe operating practices over the past decade, losses of serious magntiude are still with us. None of us can relax our guard and continuing efforts towards eliminating recurring loss areas are still in demand. . . .

"This now brings us to the second phase of our subject regarding the dangers ahead. We are all aware of the continually mounting demands for an increased share of every dollar earned by your companies from many and varied sources. Labor, equipment, supplies, power, overhead, land, drilling, transportation, etc., etc., all contribute to that demand. Additionally, it seems that every state legislature in the land looks upon gasoline as a ripe source of revenue.

"As a normal reaction to these increasing demands, cost reduction and economy are paramount throughout the industry. Of course, this has always been true, but it seems to have intensified in the last several years. Further, there is little indication of any let up in the foreseeable future.

"It has been necessary, therefore, to affect economies in plant operations on a broad front. Operating manpower has been reduced and then reduced some more. Computers are being installed to control many processes with the idea of producing lower operating costs and increased unit efficiency. Maintenance has been contracted out so there is no longer a large nucleus of reserve personnel to combat emergencies. Units are being run for much longer periods of time. Entire refineries have been integrated into the continuous flow concept. Tanks have become much larger. Plant designers are continually searching for more compact layouts in order to conserve on piping, heat requirements, land costs, and so forth. Finally, capital appropriation requests for fire protection and fire prevention equipment seem to be close to the last item on any budget.

"Let's review several of these points:

1. Operating manpower reduction – It is quite astonishing to walk through many large refineries today and note just how few personnel are at the units. When the process is running under proper conditions, there is no doubt this represents a cost savings. When abnormal conditions arise, then we believe there is more than what used to be considered the normal potential for loss. Not only are there fewer operators available for correction of the abnormal conditions, but should a piece of machinery or a control or piping fail, there are fewer personnel immediately available for fire fighting activities.

2. Computers – Great reliance is placed on these devices to control most of the operations, particularly when they are completely 'closed' into the process. We question, however, that they are always prepared to take immediate action when a control does not respond or a break or rupture occurs. As outlined in (1) above, the computer has replaced the manpower and it can only think as far as it has been programmed.

3. Maintenance – Contract maintenance arrangements have become quite popular and there is no question that they have proved to be economically successful for the plant operator. We wonder, however, if this can't be carried too far. Certainly, the performance under these contracts should be closely supervised in the future. Today's labor market and the difficulty in securing and keeping highly qualified personnel is no stranger to anyone. Maintenance contractors themselves must have these same problems so that continuous service to your particular plant could suffer. It would seem to us that any refiner would have to have better control and thereby assure himself of better performance if maintenance personnel were under his employ rather than some second or third party.

4. Increased on stream times – There seems to be an increasing spirit of competition between refiners to see who can keep a unit on stream for the longest period of time. Not too long ago 12 months was a relatively standard figure for most refining units. Then it started creeping up to 18 months, followed by 2 years, until now we hear of 3 years service. There is no question that such extended times reduce the frequency of the periods of greatest hazard to any plant; start up and shut down. On the other hand, we wonder if potentialities of more serious loss aren't being increased. Isn't it possible to encounter completely unknown equipment fatigue factors as this practice continues to lengthen?*

66 Robinson, H.S. "Is Operating Process Safety Keeping Pace with Changing Technology?" API 32nd Midyear Meeting- Los Angeles, California, May 16, 1967- Preprint No. 41-67

*Note: "On Stream" inspection techniques have made considerable progress and have added to operation safety in some cases.

5. Integrated Plants – As this concept grows in favor, loss prevention people will be faced with greatly increased challenges. Once an individual unit goes off stream for any reason, it is not just the output or the earnings of that unit that are affected. The entire plant becomes involved. In the past, there was usually sufficient plant flexibility to by-pass and store immediate products for later processing. With full plant integration, however, such will no longer be the case. If the cat-cracker goes down, you are out of the refining business until it can be repaired and brought back on stream. The speed with which this can be done in the future, as compared to some years ago, is questionable. Everyone should be aware of the equipment delivery delays now prevalent throughout the hydrocarbon processing industry. You don't order a new air blower or hydro-cracker reactor one day and expect delivery next week. Delays of from 3 to 6 months and longer are common for many, many items. In the menatime, the plant sits there producing nothing or, at least, very little, which can become very expensive.

"Until recently, most major refiners have not considered this loss of earnings exposure too seriously since their individual plants were thought to have sufficient built in flexibility or other refineries could take up the slack. On the other hand, independents with only one or two refineries have been much more aware of the problem and more frequently bought indemnity against such outages.

"It appears, however, that because of the trend towards integration, larger units, the serious delay possibilities in equipment deliveries and perhaps various other reasons, a renewed interest on the part of all refiners for insurance coverage against such losses is developing. It has been our experience that as a rule the dollar amount of loss due to lost earnings far exceeds the actual physical damage causing the original loss.

"We now, then, come back to the challenge to loss prevention people. Inherently, plant integration leads to a 'tighter' plant layout. To conserve heat and piping, the design concept has brought units closer together. Further, since there are fewer personnel, a compact unit or plant makes it easier for them to survey the unit. While things function normally, this certainly results in lower operating costs, as well as lower initial plant capital investment. On the other hand, it will call for increased diligence on the part of the maintenance and metals inspection personnel.

"Of equal concern to any underwriter is the increased mutual fire and explosion exposures between units. In our opinion, the need for more and better built-in protection against loss is greater than ever. This includes stronger underground water systems, more or larger fire pumps with positive attention to alternate power drives, greatly increased use of turrel nozzles, consideration of water deluge systems over vital machinery; full application of fire proofing materials to structural steels; improved ground drainage systems for run off of both fire water and spilled products; and remote operation from isolated locations of key block valves, by-passes, and dumps.

"Again, in our opinion, there is no ample substitute for spacing if and when an emergency develops. Further, we are not talking about the minor emergency or test field approach to fire under a set of controlled conditions. We are talking about full scale fire or explosion involvement on an immediate and possibly widespread basis which can originate from more varied occurrences than you or I can imagine. Anticipation of these events should have been in the past and should continue to be in the future, a basic concern of plant designers, contractors, and loss prevention people. Accordingly, we issued the warning as to danger ahead if these few rather simple and basic principles of plant layout and protection are lost or subverted to the principle of economy at almost any cost.

6. Tank Sizes – No review of the industry from a safe operations standpoint would be complete without some mention of the trend towards tremendous tankage for the storage of refrigerated materials. We think of such materials as natural gas, ethylene, propylene, propane, and butane stored in tanks up to 200,000 barrels and even larger at temperatures as low as -260° F. In theory, engineering has advanced to the point where the proper materials and know-how are now available for such storage. In actual day-to-day practice, we wonder if perhaps the inherent potential for loss in such storage hasn't been overlooked? A failure of the tank and release of such quantities of ethylene, for example, could lead to fire and explosion loss possibilities of tremendous proportions.

"It seems to us that the concept of 'bigness' can be carried too far unless full and ample consideration for surrounding exposures can be given. Just the value alone of the tank itself and the resulting loss in earnings due to loss of the storage facility would seem to be of prime consideration. Again, safety and loss prevention people could very well have a serious 'tiger by the tail' as this trend continues.

"As indicated earlier, the foregoing points highlight some of the dangers ahead as we see them for the general field of petroleum refining. We have said nothing whatsoever with regard to the petrochemical field in which a great majority of oil processors now find themselves. Practically all of you have one or more plants for the production of ammonia, ethylene, ethylene based products, alcohols, and so on down the line. There are very few oil companies left without a corresponding line of fertilizers and plastics . . . .

"With just a brief review of the chemical business in general, we are quite confident that operational and potential loss problems will be with us all for some time. The concept of integration and single-train operation seems to have reached more full culmination here than in the petroleum field. All that was said earlier with regard to equipment scarcities, delivery delays, labor shortages, etc., is of even more concern when manufacturing petrochemicals. Many new plants continue to be plagued with operational and mechanical difficulties in addition to which tremendous daily earnings potentials are being jeopardized . . . .

"Fire and explosion losses can result in down times for periods of several months or more. As equipment becomes more and more specialized, replacement time is increased even further. General design concepts today emphasize larger and larger plants able to produce at lower and lower unit costs. It seems to us that any operator would eventually have to ask of himself: 'Is this proposed design too

large for me to risk 30 to 40 million dollars of plant investment on? Further, what will happen to my market position if it's out of service for extended periods?'

"We believe that in many cases this question should have been asked some time ago, not only by operators, but by design and contracting firms as well. Isn't it possible to build a plant too large or too integrated? Isn't it possible to be faced with operational and loss potential problems too big to be solved by the best operators or protected by all the insurance capacity in the world? Have the days of the 'white elephants' been completely eliminated?

"We would recommend a constructive re-appraisal of this trend by all operators, loss prevention, and safety people. A close look at ultimate size is definitely a must in our opinion. Spacing within units and between units should be reviewed again. Immediate dollar savings from tightness or compactness of design should be weighed against loss of the use of the plant and the resultant earnings therefrom over extended periods. Built in fire and explosion protection and prevention equipment should not be the last items on the budget agenda. If earnings ranging from 50 to 150 thousand dollars a day or more are to be protected, extra emphasis on loss prevention spending would seem to be the only prudent course to follow. There are numerous other features and factors of a detailed nature all too voluminous to go into today, but suffice it to say that just as hard and as imaginative thinking must be applied to the loss possibilities in this industry as has gone into the engineering concepts for new designs and products.

"The immediate and long range future will be a challenge to all of you so vitally interested in keeping operating process in pace with changing technology . . . ."

Plant Layout

Much has been written on the subject of plant layout. The problem occurs, however, that even the best plant may have originally been well layed out only to have the requirements of expansion eventually to cause congestion. As crowding increases, so does the loss potential. A plant's insurance rates can be reduced if the maximum foreseeable loss can be kept at a minimum.

Austin[67] views plant layout and operation from a risk standpoint. Some of his views sound much like a warning from Civil Defense authorities.

"Losses, for example, can be, and usually are, both direct and indirect. A piece of equipment is demolished by fire: it will cost so-and-so much to replace. This is a direct loss and fairly easy to ascertain.

"But, inevitably, there also are some indirect losses in any such accident, the result of the equipment's being out of use during reconstruction. Some of these losses can be calculated and covered by business-interruption insurance- the loss of profit and the failure to earn continuing costs, for instance. But others, such as the loss of markets or the cost of retraining personnel, cannot be determined with any accuracy; these indirect losses can never be recovered through insurance. Experience has demonstrated, moreover, that the glib phrase 'any accident' requires much sharper definition than anyone had previously supposed.

"Insurance experts generally had assumed that the worst catastrophe that could happen to a refinery would be that an airplane might hit it or that some unit might explode and start a fire. The consensus was that damage would, in any event, be relatively slight. After all, until 1955 the oil refining industry had never experienced a single loss that exceeded $5 million.

"Beginning in 1955, however, we had tragically conclusive evidence that the possibility of detonations in pressure vessels and lines called for radical revision of all earlier loss projection estimates.

"We in the insurance field talk frequently of maximum foreseeable loss, or, as it is sometimes less accurately called, maximum possible loss. One insurance organization has defined this as 'the largest loss which may be expected to result from a single fire (or other peril when another peril may be the controlling factor), taking into consideration the impairment of fire protection that may be visualized on the basis of past experience.

"As the high destructive potential of detonations forced itself on our attention, we found that all previous dollar translations of maximum foreseeable loss were inadequate. Insurance companies have increased their estimate of such loss for many refineries by as much as 400 percent.

"One result of the accumulation of new knowledge about losses and accident potentials has been a thorough alteration of some old loss projection techniques. We at Standard Oil Company (Indiana), for example, have devised two new methods of calculating the maximum foreseeable loss at our refineries.

"In one method we start with an assumption of a detonation at a given danger point; then we work out vulnerability factors for all property within the assumed destructive radius of that assumed detonation.

"In the other method, which is rather jauntily called the 'Monte Carlo' method, we work from a mathematical model; then by random-chance procedures, we determine the various patterns of probable loss.

"By the use of these techniques, our insurance department has been able to establish a sound basis on which to predicate loss projections which heretofore have been solely upon underwriters' judgment . . . ."

The general methods used in these analyses to determine risks are quite similar to methods used by the Office of Civil Defense and others to study potential damage end losses to an installation in case of a bombing attack. The planning of risk reduction by management is moving in the same direction as our Civil Defense planners.

Austin says further, "In any event, this alteration of tecnniques is really less important than the alteration of attitude which has evolved not only in our company but throughout the refining industry. We have come to realize that the term 'insurance department' is misleading to the extent that it suggests an exclusive preoccupation with premiums and claims. A far more descriptive term and one which has

67 Austin, C. Henry "Risk Analysis and Safety" American Petroleum Institute 40th Annual Meeting, Division of Refining, November 14, 1960- A-12

come to be accepted by schools of business administration and the insurance industry is the 'risk-management department'. It follows that the head of the department might properly be called a risk manager.

"What has happened is that we have taken a long, second look at that question that was originally put to us: How best can we protect ourselves financially against the losses that would result from any accident we might have?

"We have come to realize late what we ought to have realized early: The best way to protect ourselves financially is by seeing to it, as far as humanly possible, that there are no accidents against which to indemnify. Of necessity, then, a company's insurance manager- the risk manager, if you will- has to take an active interest in the basic questions of safe design and safe operation.

"This active interest gives him no warrant for usurping any of the functions of line management. Safety in its application is the responsibility of line management. But, certainly, insurance specialists have an obligation to contribute whatever they can of staff assistance to help in attaining the goals of safety. At a minimum, we can reinforce with hard financial statistics all the humanitarian impulses that lead to insistence on effective safety programs.

"The insurance premium for a 40,000-bbl.-per-day fuels refinery in which the vulnerable units are properly dispersed and the fire-fighting equipment is fully adequate can run less than $60,000 a year. For a refinery in which the units are not properly dispersed, on the other hand, and in which the fire-fighting provisions are less than adequate, the annual premium can scale to more than $120,000. This potential premium savings provides management with a ready incentive for loss protection expenditures." See Figures 52, 53, and 54.

Austin concludes, "Risk management's first responsibility is the identification and the accurate assessment of the probability of losses and their consequences. But the inseparable corollary of that responsibility today is the whole matter of safety- safety in design, safety in operation- to reduce the probability of the losses and minimize their consequences.

"It is, I submit, to the vast credit of the refinery industry that we have been cleaning our own house. We have not waited for insurance underwriters or governmental bodies or anybody else to force us into a program to eliminate the sources of possible detonations. We have been self-starters. Now, it seems to me, we have to make very sure that we are also self- continuers.

"Management's action in the adoption of a program to eliminate detonations will have the simultaneous effect of reducing the frequency of lesser explosions and fires. The net result will be a significant reduction in loss ratios. This, in turn, will not only result in lower premium costs, but will also minimize occupational hazards to personnel and will serve to safeguard stockholders' investments by reducing the costly effect of catastrophic losses."

In a risk study made by the Oil Insurance Association, the minimum recommended spacing between units was determined. See Table 39.

Tank Farms

Studies of risk susceptibility of an operation nearly always eventually focus attention on crude or products in storage. As demands for through-put increase, so do storage problems. As storage tanks become larger, so does the risk and potential loss. Practices of a few years ago, and even still prevailing in some plants, actually increase the risk related to storage.

Larger and larger tank farms are being built to meet the loading and unloading demands made by large tankers carrying upwards to 2½ million barrels of crude or petroleum products. At present time a 400,000 dead-weight ton tanker is being built. A 1,000,000 deadweight ton tanker is on the drawing board. The 312,000 deadweight ton tanker is operation in 1969 is six times larger than the largest tanker operating in 1952.[68] There is no port in Europe capable of handling tankers in excess of 200,000 deadweight tons. The new tankers being built will need special terminal facilities for loading and unloading.

Johnson of Standard Oil Co. of California,[69] discusses the problem of designing a billion gallon tank farm for safety. Storing 25 million barrels of crude and products will be a common thing as our energy demands continue to "skyrocket". Time in port must be kept to a minimum, for an anchored tanker is not paying its way; the demands of industry continuously press for raw materials. At one time an 80,000 barrel capacity tank was the maximum size; now 500,000 barrel tanks are in operation.

As this trend continues, physical security must be tightened to the utmost. Guards alone are not the answer. The use of more men, dogs, electronic devices, automatic fire protection — all become of greater importance. A fire in a 500,000 barrel tank, a spill or a rupture magnify the problems discussed above. Vulnerability under some circumstances can be tremendous.

The potential of earthquake losses increases as size increases. Buckling, "walking tanks", broken floating roof seals, torn lines, collapse, and ripped sides as experienced in Alaska add additional problems for the design engineer. Rinne,[70] Civil and Structural Engineering Consultant, Standard Oil Co. of California, discusses this side problem in detail.

Johnson points put some dikes and improper drainage can be dangerous. "The old concept was to space tanks about one tank apart, shell-to-shell, and to surround each tank with a wall. (See Figure 55.) The wall may be made of earth, concrete, masonry, or steel, and its height depended upon the available area. The capacity of the diked enclosure was often equal to the capacity of the tank and sometimes

---

68 Symonds, Edward "New Tanker Trends" Energy Memo- First National City Bank Petroleum Department, July 1968

69 Johnson, D.M. "The Billion Gallon Tank Farm Design for Safety" American Institute of Chemical Engineers Meeting, New Orleans, Louisiana, March 1969

70 Rinne, John E. "Oil Storage Tanks" U.S. Department of Commerce, Environmental Science Services Administration

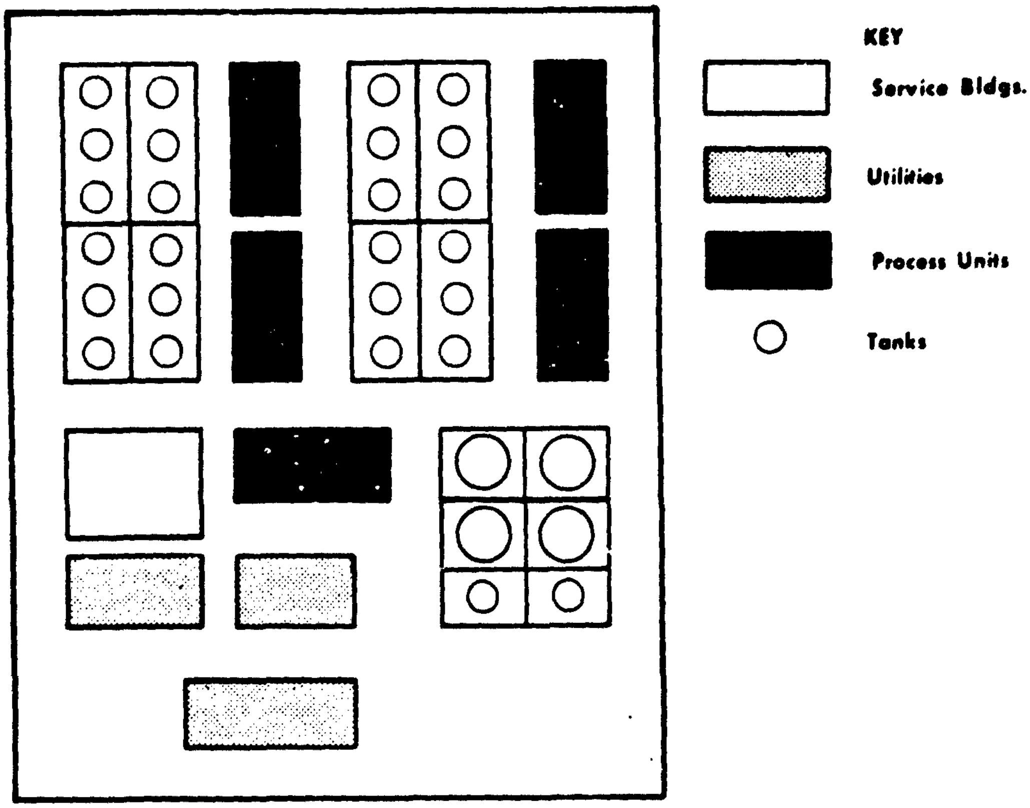


Figure 52. Illustrates a relatively poor refinery plant layout. The tanks are located in close proximity to refining units which, in turn, are located close to one another. Underwriters would hesitate to gamble their dollars on a risk such as this.

even more. In order to get the required volume of impounding, the dikes were sometimes 15 feet or higher where space was at a premium. These high dikes hampered normal operations, and made it extremely risky for men to go into these areas to take emergency action in case of a spill of oil. Several relatively small fires have grown into large-loss fires involving several tanks largely because it was too dangerous for men to go down into these deep basins to try to close valves and fight the fire. The risk of getting trapped with no rapid means of escape was too great. Also, such dikes may impede wind dispersal of vapors from a leak or spill.

"Several years ago, after several fires under these conditions, the National Fire Protection Association committee that develops the Flammable and Combustible Liquids Code (NFPA 30),[71] placed a six-foot average height limitation on tank field dikes that surround tanks.

"Another distinct shortcoming of the concept of dikes around each tank is that oil piping must normally pass through the dike. Also, in most climates, each tank basin must have a drain through the dike to carry off rain water. While these drains are supposed to have valves, and the valves should be kept normally closed, and opened only for short periods to drain off accumulated water, this is a very difficult practice to enforce. Even if drains are closed, and there are no openings in the dike for construction or maintenance work, many fires have spread from one tank basin to another. Buring oil has traveled through channels formed by failure of piping on both sides of the dike, or through holes made by movement of the piping through the dike from thermal stresses generated by fire exposure, which weakened the dike and permitted liquid to flow through. In some cases, porous material has been used for dike construction, which permitted substantial leakage of liquid through the dike. Impounding dikes have generally not done the job intended. All too often, spilled liquid gets past them, and they tend to impede emergency action.

"The disastrous tank farm fires have generally followed a sequence about like this: Normal operations require that most tank valves be open to permit transfer into and out of the tanks. A spill of liquid has occurrud, often by overfilling one of the tanks due to operating error, often involving mistakes in gaging the level of tank contents. The liquid flows around the tank and into the lowest area which in many cases is occupied by the piping. The spilled oil has flowed to a point where it has become ignited and the fire

71 Flammable and Combustible Liquids Code (1966), National Fire Protection Association, 60 Batterymarch Street, Boston, Massachusetts 02110

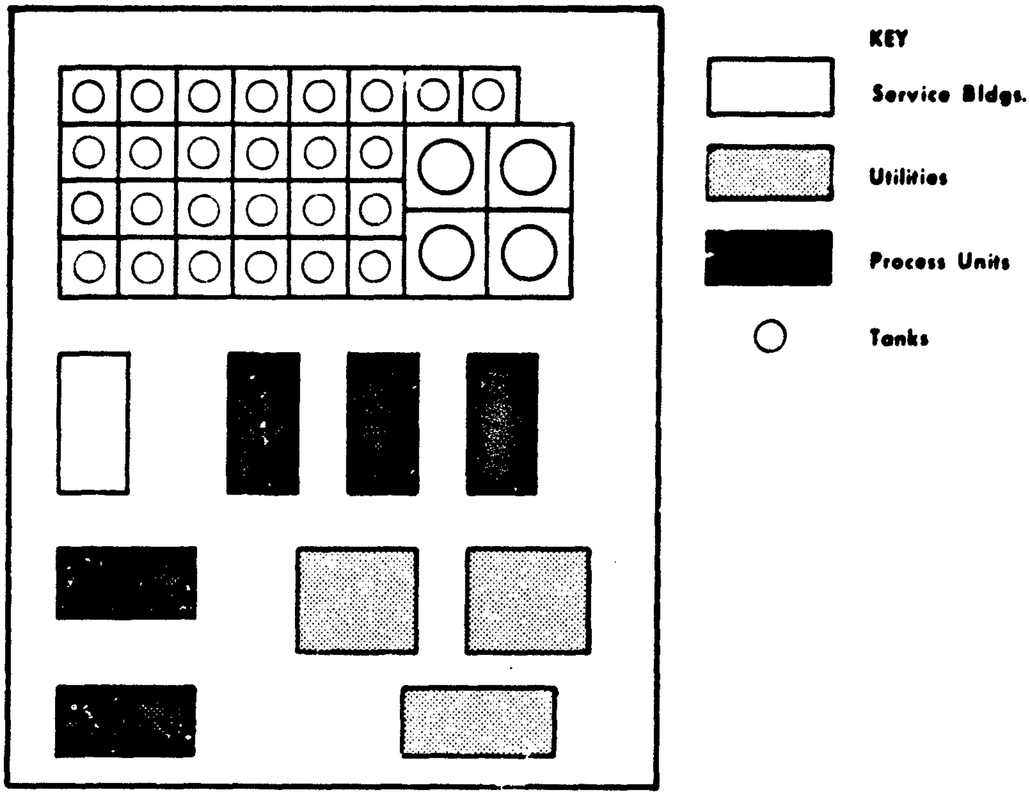


Figure 53. Illustrates a good refinery layout. The various elements of the plant are well seperated. Insurance underwriters would be willing to assume a much greater dollar amount of insurance on this plant than on the previous one.

flashed back along the pipeway to the tank. If the tank was full to overflowing before the fire, the heat of the fire caused expansion of the liquid causing further spillage of fuel into the fire area. Many older tanks had cast iron valves and fittings, as well as threaded tank connections. These quickly failed when exposed to severe heat. Even if the tank had steel valves and connections, the thermal stresses on piping soon stretch flange bolts so that leakage occurs. Also, flexible couplings that rely on a combustible gasket, or will permit the ends of a pipe to pull out of the coupling, may permit piping failure when exposed to fire or unusually high stresses imposed by fire exposure. When piping fails, and the tank valve is open, the contents of the tank run out and add fuel to the fire. When the tank is no longer cooled by liquid inside, the steel softens and the tank collapses into a heap. The increased fire places such strains on the piping and dike walls that in most cases burning liquid gets into the adjoining tank basin and starts the process all over again. And so the fire spreads from one tank to another . . . ."

Johnson continues, "As discussed earlier, the demand for much larger storage tanks for flammable liquids is here, and it is being met by the petroleum and chemical industry. The question is not really how big a tank is safe, but rather how can we make a big tank and large storage farms safe. Tank size, nor number of tanks on one property, is not the critical criteria. Tanks must be built to design criteria that insure physical integrity of the tank against all reasonably expected forces such as tank contents, ground settlement or movement, wind or snow. American Petroleum Institute Standard API-650, Welded Steel Tanks for Oil Storage,[72] is generally accepted throughout the United States as a good code.

"In most areas, control of losses through evaporation from fixed roof tanks make it economical to store volatile oils and crude oils in tanks having floating roofs. Non-volatile oils can be safely stored in fixed-roof tanks. Crude oil stored in floating roof tanks is virtually immune from possibility of boil-over even if the tank is ignited. During the thirty years or more that crude oil has been stored in floating-roof tanks in many areas, I know of no instance where a true boil-over has occurred. Therefore, there is little to be gained by leaving vast distances between tanks. National Fire Protection Association Standard NFPA-30 specifies a minimum shell-to-shell spacing of 1/6 the sum of the

72 "Welded Steel Tanks for Oil Sotrage" Third Edition, July 1966, and "Supplement to API Standard 650" Third Edition- December 1967- American Petroleum Institute, 1271 Avenue of the Americas, New York, New York 10020

RISK DISPERSAL

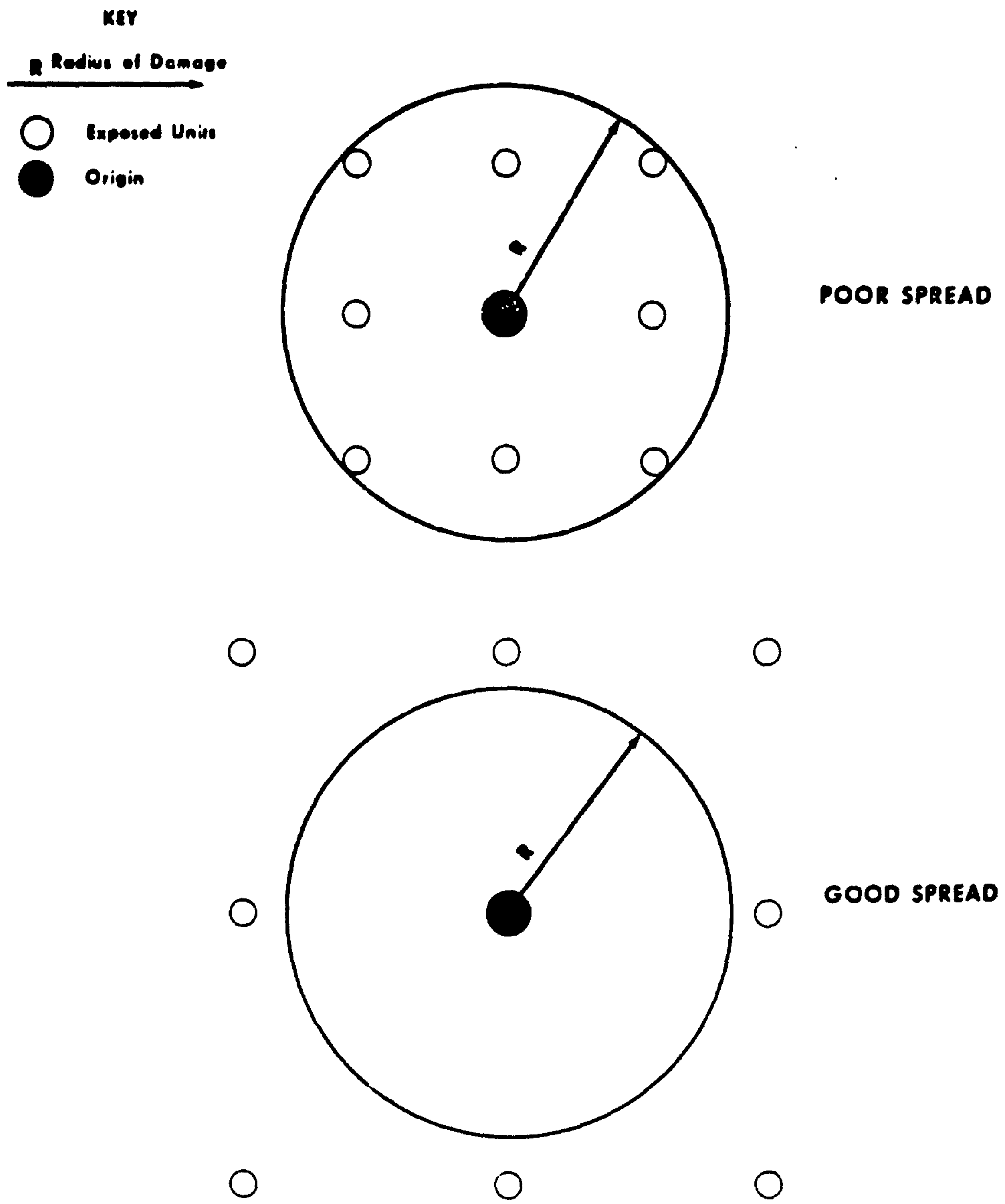


Figure 54. Risk Dispersal

The purpose of Figure 54 is to illustrate the principle of radius of destruction as applied to dispersal of risk. In the good layout only the unit of origin will suffer damage, whereas with the poorer lay-out all the exposed units will be damaged.

Table 39. Oil Insurance Association

GENERAL RECOMMENDATIONS FOR SPACING IN PETROCHEMICAL PLANTS

MINIMUM DISTANCE IN FEET

	PROCESS UNIT-HH	PROCESS UNIT-LH	TANK FARMS-HH	TANK FARMS-LH	PRODUCT WHSES-LH	SHIP'G. & REC'G.-HH	SHIP'G. & REC'G.-LH	SERVICE BLDGS.	BOILER AREA	FIRE PUMPS	EMERGCY CONT'S.	WTR. SPRAY CONT'S.	TURRET NOZZLES	EMERG'CY FLARES	PILOT PLANTS	LARGE COOL'G TWRS	FIRE HYDRANTS	
PROCESS UNIT- HIGH HAZARD [B]	200									250	100	50[5]	50 - 150 TO CENTER OF TARGET	FOR 100' FLARE THAT IS 25' ABOVE SURROUNDING EQUIP'T. USE 300'	200	150	50 TO 250	
PROCESS UNIT- LOW HAZARD	100	50								150	50				200	100		
TANK FARMS - HIGH HAZARD [C]	250[1]	250[1]	1½ DIA. LARGER							250		100[7]			250	250		
TANK FARMS - LOW HAZARD	200[2]	100[3]	ONE DIA LARGER	½ DIA APART						200					200	200		
PRODUCT WHSE. LOW HAZARD [D]	150	50[4]	250[1]	100[3]	50[4]					200					200	150		
SHIPPING & RECEIVING HIGH HAZARD [E]	200	200	150[2]	100[3]	150	50				150	100	50[8]			200	200		
SHIPPING & RECEIVING LOW HAZARD	150	100	100	50	20	50	-			100	50				150	150		
SERVICE BLDGS. [F]	200	100	200	100	100	150	100	SEE BLDG. SHEET		100					200	100		
BOILER AREA	200	150	200	150	100	200	100	100	-	-					200	100		

RECOMMENDED SPACING WITHIN PROCESS UNITS

	REACT.	COMP.	TANKS	FRACT. EQUIP'T.	CONT. ROOMS
REACTOR	25[6]				
SMALL COMPRESSOR HO. OR PUMP HO.	40[6]				
INTERMEDIATE STGE. TKS. HIGH HAZARD RUNDOWN-FEED	100[7]	50	ONE DIA.[8]		
FRACTIONATION EQUIP'T.[I]	50	30	75		
CONTROL ROOMS	50[6]	40	75	40	10

A. DISTANCE BETWEEN PROCESS UNITS IS MEASURED FROM BATTERY LIMITS.

B. A HIGH HAZARD PROCESS UNIT HAS EXPLOSION CLASSIFICATION UNDER PETROCHEMICAL SCHEDULE OF E-4 OR E-5.

C. HIGH HAZARD TANKS ARE CLASS "D" UNDER THE ABOVE SCHEDULE. CLASS "E" REQUIRES SPECIAL CONSIDERATION.

D. HIGH HAZARD PRODUCT WAREHOUSES CONTAIN UNSTABLE MATERIALS, LOW-FLASH FLAMMABLE LIQUIDS, OR HIGHLY COMBUSTIBLE SOLIDS. THESE REQUIRE SPECIAL CONSIDERATION.

E. HIGH HAZARD SHIPPING & RECEIVING DENOTES BOTH STABLE & UNSTABLE MATERIALS WITH FLASH POINT BELOW 110°F.

F. SERVICE BUILDINGS INCLUDE OFFICES, GATE HOUSES, CHANGE HOUSES, LABS, SHOPS, GARAGES, MAINT. WHSES., CAFETERIAS, HOSPITALS, ETC. EXPERIMENTAL LABS CLASSIFY AS PROCESS UNITS.

G. KEEP OPEN FLAMES 100' FROM VAPOR HAZARD AREA.

H. DEVIATION FROM THESE DISTANCES REQUIRES SPECIAL PROTECTIVE INSTALLATIONS SUCH AS FIXED FOAM SYSTEMS, WATER SPRAY, AUTOMATIC SPRINKLERS, FIRE-SYSTEM GRADING OF 4 OR BETTER, OR SUPERIOR CONSTRUCTION.

I. IN BORDERLINE CASES, HIGH VALUE REQUIRES HIGH HAZARD CLASSIFICATION.

J. VERTICAL STORAGE TANKS SHOULD BE INDIVIDUALLY DIKED. IF NOT, CAPACITY IN SINGLE DIKE SHOULD NOT EXCEED 25,000 BBLS. FOR HORIZONTAL STGE. TANKS, MAXIMUM IS 400,000 GALLONS PER GROUP, WITH 100' BETWEEN GROUPS, OR OTHER SUITABLE ARRANGEMENT.

1. FOR SPECIFIC VERTICAL TANK, USE 5 DIA.
2. FOR SPECIFIC VERTICAL TANK, USE 4 DIA.
3. FOR SPECIFIC VERTICAL TANK, USE 3 DIA.
4. STD. FIREWALL & SPRINKLERED WHSE. ACCEPTABLE. LIMIT WHSE. TO MAXIMUM 25,000 SQ. FT.
5. TWO STATIONS DESIRABLE.
6. BARRICADES DESIRABLE FOR HAZARDOUS REACTORS.
7. REDUCE 50% FOR WATER SPRAY ON TANKS.
8. OVER 100,000 GALLONS REQUIRES SPECIAL CONSIDERATION.

JULY 1963

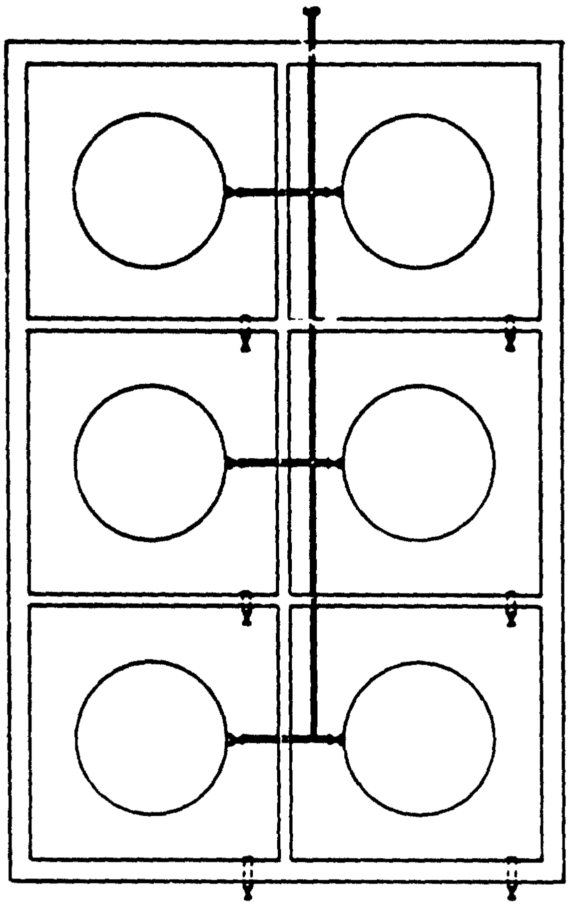


Figure 55. The Old Concept of Tank Field Layout and Impounding.

diameters of two adjacent tanks. Some oil companies place floating-roof crude tanks 1/2 diameter apart with a minimum of about 100 feet. The primary purpose of this spacing is to provide adequate space for good drainage away from the tanks into a safe location, as discussed further below.

"Whether the tanks have floating roofs or fixed roofs, piping connections to the tank should be made of all-welded steel so strong that the piping out to the first flange will be an integral part of the tank. The first valve should be constructed of steel and be located no more than a few feet from the tank shell. This is very important because if the tank valve is closed, there will be very little possibility of the tank contents being released, regardless of what happens in the vicinity of the tank. Piping outside the valve should also be of welded steel and be designed with adequate flexibility to prevent excessive stresses on the tank valve or piping connection through settlement or movement of the tank or piping. Flexibility should be provided through 'dog legs', rotating flanges, or other devices that will not be weakened even though exposed to fire. Flexible joints employing combustible gaskets or slip joints should be avoided.

"One of the greatest sources of spilled oil in tank fields is from overfilling a tank. Tape gages that can be read from ground level or from a remote location make it much easier to keep track of liquid level in individual tanks and tend to eliminate errors.

"All of the above design criteria are very important in the design of tanks in the billion-gallon tank farm. I think they are generally followed by most operators of large flammable liquid storage facilities. Therefore, they can hardly be classed as a 'new concept'.

"The design concept that is relatively new is in the tank field layout and drainage pattern that controls the flow and impounding of any oil that is spilled. This relatively new approach is designed to prevent a small fire from becoming a large fire and involving more than one tank. Figure 56 shows a typical layout on a relatively level site. The tank foundations are built up two to three feet above normal grade and the ground slopes away from the tanks in all directions except in the vicinity of the tank valve, at a minimum slope of 1%. Tank field piping runs midway between

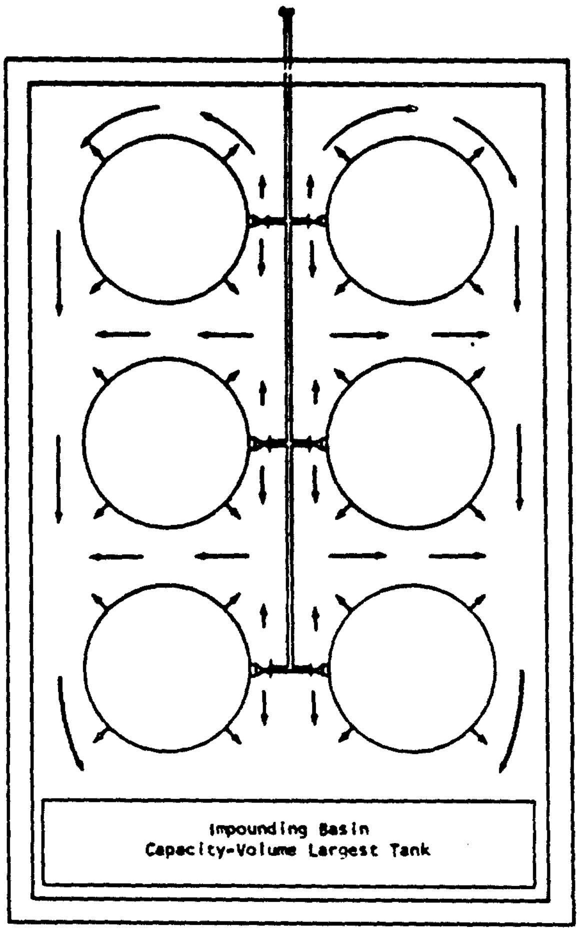


Figure 56. The newer concept of tank field layout and drainage, including remote impound.

two rows of tanks and is located over a high point ridge in the tank field. Thus, the tank valves and the piping are located over high ground. Any spill of oil from the tank, the tank valve area, or the pipeway flows away from these facilities into drainage channels that carry it away from the tanks to channels located adjacent to the access roads into the tank field. This drainage channel must be sloped towards an impounding basin located at the edge of the tank field. Normally this basin should have a capacity for all the oil that could be discharged from the largest tank in the field. One practical criteria for sizing the drainage channels is for them to have capacity for the largest stream of oil that could be discharged from a broken pipeline under maximum normal pump pressure, or by gravity from one of the tanks.

"With this type of grading and drainage, there is the greatest likelihood that the tank valves of all tanks in the tank field will be accessible and the valves and piping will not be damaged by a fire even if spilled oil is ignited. The oil will run away from the tanks and down into the separate impounding basin where, even if burning, it will do no significant damage. If not ignited, it can be accumulated in the impounding basin and recovered. This concept will normally require no more total land nor be any more expensive than the old concept of individual dikes around each tank or small group of tanks.

"Where tankage is located on sloping ground, such as a hillside, this concept is usually more easily applied. The impounding basin can often be provided by constructing an earthen dam across a natural drainage channel.

"A tank field containing 25 one million-barrel tanks or fifty 500,000-barrel tanks may involve an investment in tankage, piping, and contents approaching $100 million. This magnitude of investment must be safeguarded by building the tanks to standards that will assure that they can withstand any reasonably expected force, manmade or natural. Conditions surrounding the tanks must be such that an error in operation or a mechanical failure can be controlled so as to minimize damage to the tank and its contents, and to virtually eliminate the possibility of other tanks being involved.

"It is believed that the 'new concept' described here will accomplish this objective. It is consistent with provisions in several nationally recognized fire prevention codes such as the Flammable and Combustible "Liquids Code of the National Fire Protection Association71 and the Fire Prevention Code of the American Insurance Association.[73]

Loss Prevention and Control

The American Insurance Association tabulates for easy references some vital points of loss control.[4]

"Prevention and control essentially deal with the elimination of those conditions which make an explosion possible. This is accomplished through the application of basic safety standards, acceptable safe practices and good engineering judgment. Primary standards and safe practices applicable under the various explosion categories are listed below.

"1. Rapid release of energy through the ignition of atmospheric mixtures of flammable gases, vapors or combustible dusts within the explosive range.

"(A) Flammable liquids should be stored and processed in accordance with the requirements of NFPA Standard No. 30 'Flammable and Combustible Liquids Code'.

"(B) Flammable gases should be stored and processed in accordance with the requirements of applicable standards for the materials involved. The following standards may be used as a guide: NFPA Standard No. 58 'Liquified Petroleum Gas' and NFPA Standard No. 567 'Gaseous Hydrogen Systems'.

"(C) Combustible dusts should be handled and processed in accordance with the materials involved. Basically, NFPA Standard No. 63 'Dust Explosions- Industrial Plants' should serve as a guide. More detailed recommendations on specific materials are contained in NFPA Standards covering pulverized fuels, starches, flour, aluminum, magnesium, plastics, sulphur, spices, wood and sugar.

"(D) All sources of ignition including open flames, electrical hazards, smoking, etc. should be eliminated from hazardous areas. The requirements of Article 500 of the National Electrical Code and NFPA Standard No. 77 'Static Electricity' should be observed.

"(E) Processes should be designed so that flammable liquids, gases, vapors, mists and dusts are contained in closed systems. Combustible gas indicators may be necessary to monitor some high hazard areas. Equipment should have overpressure relief facilities in accord with applicable standards.

"(F) Inerting systems and the application of inerting gases should be used for the prevention of fires and explosions in containers or enclosures which hold hazardous quantities of flammable gases, vapors, or combustible dusts. Reference should be made to NFPA Standard No. 69 'Inerting for Fire and Explosion Prevention'. Explosion suppression systems should be used wherever required.

"(G) Process instruments and control devices should not introduce a new hazard into the system. Such equipment should meet the requirements of the National Electrical Code of NFPA Standard No. 493 T 'Intrinsically Safe Process Control Equipment for use in Hazardous Locations'. Such equipment should also be kept in purged enclosures in accordance with NFPA Standard No. 496 'Purged Enclosures for Electrical Equipment in Hazardous Locations'.

"(H) Process areas with serious explosion hazards should be protected by fast-acting automatic water deluge systems installed in accordance with NFPA Standard NO. 15 'Water Spray Systems for Fire Protection'. Combustible gas detection coupled with ventilation and deluge water spray systems may be used to dissipate vapor clouds and produce an 'air washing' of the hazardous atmosphere.

"2. *Rapid release of energy through the detonation of deflagration of unstable (potentially explosive) chemicals after exposure to an initiating force or energy.*

"(A) Unstable chemicals may suddenly release energy in the form of heat, fire or explosion when exposed to an irritation force or energy in the form of impact, shock, fric-

73 Fire Prevention Code, 1965 Edition, and 1966 Revisions, American Insurance Association, 85 John Street, New York, New York 10038

tion or heat. Such conditions should be avoided. Reference should be made to NFPA Standard No. 49 'Hazardous Chemicals Data' for information and identification of unstable chemicals. Unlisted suspected chemicals should be evaluated before use.

"(B) Unstable chemicals should be stored in suitably isolated buildings to give maximum protection to employees and the public. The quantities of these chemicals brought into the operating area should be kept to a minimum. Guidance can be found in American Insurance Association Research Reports No. 11 'Fire, Explosion and Health Hazards of Organic Peroxides' and No. 12 'Nitro-paraffins and Their Hazards'. Explosion venting of buildings and equipment should be undertaken whenever the material indicates feasibility. Some materials cannot be vented, as the velocity of the explosion it too great.

"(C) Unstable chemicals require special supervision for storage, handling and processing. Personnel should be carefully selected for this work.

"(D) Unstable chemicals should be transported in accordance with the regulations of the Department of Transportation and the suggestions of the American Insurance Association: Suggested Guide for State Action on Safety from Fire, Explosion and Health Hazards in Highway Transportation of Extra-Hazardous Commodities.

"(E) Information on the storage and handling of unstable chemicals is available covering the following: responsibility, procedures, housekeeping, permit system, tools, security, waste disposal, isolation, processing, material transfer, contamination and other special considerations. Reference should be made to MCA Safety Guide SG-7 'Storage and Handling of Shock and Impact Sensitive Materials'. U.S. Army Ordinance Manual and U.S. Naval Ordinance Publication- NAVWERPS OP 3237- 'Safety Principles for Laboratory and Pilot-Plant Operations with Explosives, Pyrotechnics and Repellants'.

"3. *Rapid release of energy through decomposition or exothermic chemical reactions.*

"(A) All chemicals and processes suspected of being in this category should be thoroughly examined and tested to detect those materials and processes which show dangerous exothermic tendencies. Many test procedures have been established under the guidance of the JANAF (Joint Army Navy Air Force) group. A differential thermal analysis (under pressure) will aid in the evaluation and is strongly recommended for potentially explosive operations.

"(B) Those chemical processes which show dangerous exothermic tendencies should be carefully operated to assure safe processing within controllable limitations. The limitations should cover the rate of reaction, temperature, pressure, shock, adiabatic compression and other pertinent factors indicated by tests or technical literature. Controls and instrumentation should be utilized to detect any unusual conditions which should then force the process to revert to a *fail-safe* condition (See section on Chemical Process Evaluation).

"(C) Overpressure relief for storage or process vessels should conform to applicable standards. Back-up equipment in the form of safety relief valves or rupture (pressure relief) diaphragms may be used. This equipment should be operable at all times. Frequent inspection and maintenance is recommended. References can be found in the ASME Pressure Vessel Code.

"(D) The elimination or protection of sight glasses is strongly recommended for this type of process equipment. Differential level indicators, magnetic floats or reflex sight glasses with excess flow valves have been suggested. Combustible gas detection systems coupled with rapid ventilation and deluge water spray systems should be considered.

"(E) High pressure process areas involving exothermic reactions should be well isolated from other plant and public facilitieis. The nature of the process, quantity and type of materials and the anticipated hazard potential should determine the distance. Barricades, blast walls and other special protective features may be used to supplement distance.

"(F) Containers, tanks, tank cars and vessels should be thoroughly cleaned after use to prevent contamination of the process with a sensitizing material. Incompatible materials should be separated from reactants.

"(G) In an emergency, special dump, blowdown or quench systems may be used to remove hazards from the process area or to quench the hazardous conditions. Emergency cooling systems are also used to slow down reactions.

"(H) All pressure vessels, instrumentation and auxiliary units should be periodically inspected and recommendations made regarding safety and maintenance.

"(I) Water cooling towers are extremely important to the safety of the plant and process operation. The water serves as the source of fire water coolant and safety control in exothermic type processing. Water cooling towers should be located, constructed and protected in accordance with NFPA Standard No. 214 'Water Cooling Towers'."

"4. *Rapid release of energy through the mechanical failure of a pressure container as a result of mechanical defect or the generation of excessive pressure.*

"(A) Failure of pressure vessels and auxiliary equipment may result from a variety of causes. These have been placed in five major classifications: (1) Design; (2) Materials; (3) Base Metal Defects; (4) Fabrication; and (5) Service. It is possible for failure to result from a combination of these causes.

"(B) Prevention of pressure equipment failure requires good design in conformity with the ASME Pressure Vessel Codes that apply.

"(C) A quality control of all base metals, welding materials and other components is an essential for pressure vessel fabrication. Testing of materials should indicate what might be anticipated under actual service conditions.

"(D) Fabrication of large pressure vessels presents many problems. Welding without proper controls may produce common defects and failures. Heat treatment for stress relief is an essential part of good fabrication in units where service results in mechanical as well as thermal fatigue.

"(E) Cleaning of equipment after fabrication should be carefully undertaken so as not to develop adverse corrosion effects on the vessel. Cleaning should not damage piping or other equipment parts.

"(F) Pressure vessels should not be subjected to service conditions or environments more severe or destructive

than planned for in the original design. Some of the more common causes for service failures are as follows: excessive stresses, overpressure, external loading, thermal or mechanical fatigue or shock, overheating, corrosion, and hydrogen embrittlement. Steps should be taken to minimize the above listed causes.

"(G) Boilers, pressure vessels and auxiliary equipment should be inspected frequently by competent personnel in accordance with codes, standards, federal and state and local regulations, and insurance company recommendations.

"(H) Boilers and furnaces should be constructed, operated and maintained in accordance with applicable codes and standards, including the ASME Boiler and Pressure Vessel Code, NFPA Standard No. 85 'Fuel Oil and Natural Gas-Fired Watertube Boiler-Furnaces', and NFPA Standard No. 85B 'Furnace Explosions in Natural Gas-Fired Public Utility Boiler-Furnaces'. All equipment should be built in conformance with governmental regulations and insurance carrier requirements."

Sample Safety Check List—Loss Prevention Program[4]

1. Does the Loss Prevention Program have good management support and direction?

2. Is the Loss Prevention Organization well staffed, trained and directed?

3. Does the Loss Prevention Department understand and comply with its responsibilities?

4. Is there a good accident prevention program in the plant?

5. Is there a good health and medical aid program in the plant?

6. Does the plant present a safe working environment to all employees?

7. Is the fire protection and prevention program well developed in the plant? Is there sufficient fire protection equipment, facilities, and trained manpower to cope with the plant hazards?

8. Does the Loss Prevention Department conduct a thorough inspection and maintenance check on all safety equipment?

9. Has the plant been surveyed for explosion potential areas? Have prevention and control steps been undertaken?

10. Are all accidents, fires and explosions thoroughly investigated? Is proper corrective action taken in all instances?

Chapter VII

BUILDING BLAST RESISTANT STRUCTURES

Blast Damage to Structures

So far in this handbook, the power of the destructive forces of nature, the power of a blast from an explosion of equipment, and the power of a blast from a space detonation of gases have been discussed. There are adequate economic reasons to strengthen the weak areas in a refinery. Many managers have taken the positive stand that sensitive control equipment and other delicate apparatus need substantial protection from fires and at least normal explosions.

Research into structural strength by the Office of Civil Defense gives considerable encouragement as to the resistance of some refinery equipment to blasts. Most buildings need more consideration in their design, especially if they are built of concrete block, cinder block, wood, or sheet metal. Studies made by Advance Research, Inc.[74] for the Office of Civil Defense, Table 40, is a summary of their findings relating to refinery equipment.

The shape of the building has much to do with its resistance to a blast. This point has been mentioned several times. In Nagasaki, after a 20 KT bomb drop, and this is small, a factory a half mile away from ground zero was demolished. Its two smoke stacks of reinforced concrete were left standing. These tower-like structures are not pressure sensitive but are drag sensitive to wind pressure created by its velocity. (Dynamic pressure explained previously).

Table No. 40 shows that towers and structural supports do not fail until subjected to 5 to 8 lbs. overpressure. Their *anchor bolts* failed causing toppling of the structure. A strong steel frame can stand as much as 10 lbs overpressure (a dynamic loading of 288 lbs./sq. ft.).

Much testing of the durability of buildings was done at the Nevada test site. Small structures with light load-bearing walls completely collapsed in a relatively small blast. These structures are sensitive to overpressure; roof trusses buckle by compression.

A blast overpressure of 2-3 psig will crack 8 to 10 inch concrete (non-reinforced) and cinder block walls. Brick walls are stronger, failing at 7 to 8 psig blast overpressure.

A 20 megaton nuclear bomb, 1000 times larger than the one dropped in Japan, exploding at optimum height 20 miles away from a plant could create a blast overpressure of 2.4 pounds on its structures. The control house, switchgear house, warehouse, laboratory, office buildings and power plant, some control wiring, water coolers and similar equipment would be seriously damaged. Most buildings within a plant are particularly susceptible to space explosions as well as to fires and equipment failures. The use of glass in windows facing a unit is particularly dangerous. High velocity broken glass is quite formidable and dangerous, not only to life, but also to sensitive equipment that might be in its way.

74 Fernald, Olaf H. et al "Critical Industry Repair Analysis—Petroleum Industry" Advance Research, Inc., For Office of Civil Defense—Report CIRA-4 October 1965

Structural Failures

In 27 A.D., 50,000 people, as said in an old report, were mutilated or crushed to death at a gladiatorial show. The event was the collapse of the Roman Amphitheater. A report of the cause referred to the builder. "He neither rested its foundations on solid ground nor fastened the wooden structures securely. The packed structure collapsed, subsiding both inwards and outwards and precipitating or overwhelming a huge crown of bystanders." This is one of the first records of an architectural failure, and it is just one of the many great disasters of history. A lesson is to be learned from the many past accounts of accidents. Ducommun[75] said, "It should not be necessary for each generation to rediscover principles of process safety which the generation before it discovered. We must learn from experience of others rather than learn the hard way. We must pass on to the next generation a record of what we have learned." This is a fundamental in process safety design.

Foundation failures are not limited to structures of ancient times. Local soil problems (some were discussed under earthquakes) are everywhere regardless of the geology of the underlying rocks. Many structural failures are related to shifting soil. When such occurs in a chemical processing unit, ruptured lines usually cause a fire, an explosion, or a detonation. Often failure of equipment is related to some foundation problem.

Soils and Structures

Booklet 8 of the American Oil Co. Safety Series[75] discusses foundations and structures. "Allowable soil bearing loads for new facilities should be established only after the soil at the proposed site has been investigated. *In addition, at least one test boring should be made at the foundation site for each major tower or other tall structure,* particularly if there is history of uneven settlement or other uncertain soil conditions in the vicinity. All test borings should be plotted in their entirety. Where soil conditions require the use of piling, it may be necessary to drive test piles for load tests.

"The bearing plane of major footings should not be higher than the invert elevation of nearby sewers or piping, unless special precautions, such as encasement in concrete, are taken to prevent washouts or unstable bearing conditions. All major foundations *must* extend below the soil frost line to protect against settlement or displacement from heaving. Foundations for pumps, compressors, and other machinery which produce vibration require additional special attention.

"Foundations *must* be designed to be stable under all conditions of loading (Figure 37*) including wind (hurricane

75 Ducommun, Jesse C. "Engineering for Safe Operation" American Oil Co. Booklet No. 8, 2nd edition, page 51, 1966

Table 40. Summary of Blast Damage to Structures

Over-pressure (psi)	Controlhouses		Crude Units					Fluid Catalytic Cracking Units (FCCU)				
	Steel Roof Decking and No Frame	Precast Concrete Roof and Steel Frame	Steel Frame bet. Vessels	Atmos./Vacuum Towers		Fractionator Towers		Regenerator Tower		Reactor Tower		Fractionator Tower
				Rectangular Conc. Frame	Octagonal Conc. Frame	Rectangular Conc. Frame	Mounted on Conc. Pedestal	Rectangular Steel Frame	Rectangular Conc. Frame	Rectangular Steel Frame	Rectangular Conc. Frame	Mounted on Conc. Pedestal
0.5	Windows shatter	Windows shatter										
1.0	Roof collapse (switchgear room)	Frame deformation										
1.5	Roof collapse (control room)	Roof collapse (all rooms)										
	West Blast: Partial roof collapse (control room) North and South blast			Note: Atmospheric & Vacuum Towers	Note: Vacuum Towers only					Note: Reactor & Fractionator supported by same frame		
3.5	Conc. block walls fail	Conc. block walls fail	Conc. brackets fail causing frame collapse									
4.5							Anchor bolts yielding					
5.0								Leeward columns buckle East or West blast				Anchor bolts yielding
5.5				Conc. frame cracking		Conc. frame cracking						
7.0				Conc. frame collapse	Conc. frame cracking	Conc. frame collapse	Vessel & foundation overturn	Overturns Easterly blast		Leeward cols. buckle. East blast		Overturns Anchor bolts fail
7.5					Vessel anchor bolts fail causing frame collapse					Leeward cols. buckle. West blast		
8.0								Overturns Westerly blast			Concrete frame cracking	
8.5									Conc. frame cracking			
10.0		Steel frame collapse										
12.0										Steel frame overturns	Conc. frame collapse	
16.0									Conc. frame collapse			

Source: Advance Research, Inc.

Table 40. Summary of Blast Damage to Structures (cont'd)

Over pressure (psi)	Light Ends Units: Debutanizer – Mounted on Pedestal and Large Footing	Light Ends Units: Vapor Recovery Unit – Rectangular Steel Frame	Furnaces Pipe Still: Atmospheric	Furnaces Pipe Still: Vacuum	Maintenance Building	Water Cooling Tower	Flares: Tower Supported	Flares: Guyed	Pipe Bands: Steel Frame	Pipe Bands: Concrete Frame	Boiler Stack F.C.C. Unit	TEL Building	Bulk Terminal	Storage Tanks: Cone Roof	Storage Tanks: Floating Roof	Storage Tanks: Spherical
0.3					Corrugated Asbestos Siding fails	Corrugated Asbestos Louvers fail										
1.5			Moves slightly* from original position.	Moves slightly* from original position.								Tile walls fail	Roof of Admin. Bldg. collapses. Cone roofs of tanks collapse	Empty tank uplift	Empty tank uplift	
2.0																
3.0					Steel frame deformation		Steel frame overturns. [illegible]									
3.8						Tower collapses			Steel frame deformation	Concrete frame cracking				Tanks (0.5 to 0.9 filled) uplift over this range depending on height-to-diameter ratio and diameter of tank.		
4.0							Steel frame overturns. Blast squarely oriented									
5.0					Brick walls collapse. Severe frame deformation.					Concrete frame collapse.						
6.0		Steel frame collapse.	Stacks collapse	Stacks collapses	Steel frame collapses				Steel frame collapse.							
6.5			Steel frame collapse	Steel frame collapse							Stack and foundation overturn		Tanks uplift (0.5 to 0.9 filled)			
7.0												Steel frame* deformation				Support deformation (full) support
7.5																Support deformation (empty)
9.0																Overturns (full)
9.5	Vessel overturns											Steel frame collapse.				Overturns (empty)
10.0																
10.5																
11.0								Collapse above middle collar								
15.0								Complete collapse								
20.0															Roof Collapses	

forces where applicable), vibration, test conditions, platforms, piping, and bundle pulling. *Normally, vessel foundations should be designed so that the vessel can be water filled.* (*Figures not reproduced here).

"Structures *must* be designed for all loading conditions that may be encountered, including wind, vibration, and testing. Particular attention should be given to critical support and bracing components and connections and to the overturning safety factors on tall structures.

"Figure 38* shows one of the connections that failed during the collapse of the reactor-generator structure on a catalytic cracking unit (Figure 39*) being tested with a water load.

"It is important that the structural design provide for unequal distribution of loads resulting from unequal deflection of component supports. Eccentric connections should be avoided if possible. Each structural design *must* be thoroughly analyzed.

"Sufficient ladders and platforms should be installed to permit adequate access for normal operation and equipment maintenance (plus emergency access). Ladders on tall towers and structures should be offset at intervals usually 30 feet maximum. Platforms and other elevated structures should have guards, such as toe-plates, to prevent tools and other objects from falling on personnel and equipment below.

"Unfireproofed steel structures should be protected from external corrosion. Galvanizing or other special protection may be justified for structures subjected to salt water mist or spray or other corrosive atmospheres.

"Structures that are constructed of hollow members, such as supports made of pipe, *must* be capped or otherwise sealed to prevent water accumulation and subsequent corrosion or freezing."

Foundations in areas of faults (earthquakes) need to be of special design. Some bearing capacity tests ignore boundary effects related to soil character and composition. A simple loading test usually is not enough. The design of a suitable foundation for any structure of height is a specialists job for one knowledgeable of both geologic and soil conditions of the area in question. There is frequently a tendency to error on the light weight minimum legal side, for foundations are expensive and are usually unseen. Safety codes are meant only as a minimum guide and are not adequate for some peculiar conditions. Each new area, even near existing equipment, is a special condition and needs special attention.

One of the frequently encountered weak points in refinery construction is in bolt strength and size when viewed in light of vessel and tower strength. Undersized bolts or bolts of the improper alloy yield and shearing occurs before the structural steel members they tie to the foundation fail; tall structures topple, crushing all that is beneath them - (often the control house).

The refiner is constantly striving to make plants safer; the record is good, but even the loss of one life is a catastrophe to the family in which the loss occurs. By permitting housing to be developed near a plant, a harbor, or terminal area - or by allowing manufacturing plants or offices to exist nearby - the risk of life and property loss is increasing. The refiner's risk not always confined to his fence line. Conversely, a plant can be damaged by problems developing outside the installation.

Allan and Athens[76] discuss the explosive forces expected from a refinery accident.

"The potentially hazardous nature of accidental explosions in chemical process plants requires that each facility be designed to minimize the probability of their occurrence and to reduce the losses . . . . Such protection is commonly achieved by the separation of hazardous and vulnerable components of the facility, by the erection of barricades and protective walls, and by remote operation of hazardous equipment.

"The degree of success depends upon the ability to estimate the character of the explosion, the aerodynamic loadings it will produce, and the response of the exposed structures . . . . Furthermore, structures exposed to the explosive blast may be complex and therefore, in many instances, the dynamic response rather than the effects of static loadings must be considered.

"Since the methods of predicting the ability of specific structures to withstand the effects of accidental explosions must necessarily be based on a simplified description of the processes involved, the results can only be approximations of the actual conditions that may exist. As a result, a generous factor of safety must be applied to ensure than an adequate design is achieved."

This paper shows methods of calculating forces from various types of explosions. The authors point out, "The general methods of dynamic analysis of structural elements exposed to blast loadings include three steps: the establishment of the free-field blast input, the definition of "the manner in which the input 'loads' the structural element, and the calculation of the response characteristics of the structure to this loading."

Czerniak[77] discusses the importance of foundations and points out that the lateral loads caused by wind pressure or earthquakes are considerable. He states, "Wind and earthquake loads are often neglected in foundation design for the hydro-test condition." There has been vessel collapse during hydro-tests at several plants.

"The required size of the foundation is determined by trial and error. It should be addquate to withstand the most adverse loading imposed during the following conditions:

Empty conditions
Operating condition
Hydro-test condition
Empty condition with wind
Empty condition during earthquake
Operating condition with wind
Operating condition during earthquake"

Tall structures, such as towers and stacks, located in potentially high wind areas, need vibration dampening devices

76 Allan, Donald S. and Athens, Peter "Influence of Explosions on Design" Arthur D. Little, Inc. American Institute of Chemical Engineers, Loss Prevention Manual Vol. 2, page 103, 1968

77 Czerniak, Eli "Foundation Design Guide for Stacks and Towers" The Fluor Corp., Ltd. Hydrocarbon Processing, Section 1, page 95, June 1969

for added protection. These could be refractory linings, internal rings, fins, and spoilers which are sometimes added in an attempt to decrease the formation of von Karman vortices. Vortices can induce critical vibrations transverse to the direction of the wind flow. "The spoilers are steel strips welded edgewise to the stack and wound around its upper third in a helix form. The spoilers add to the projected area exposed to wind, and consequently the overturn moment caused by wind in increased."

Wind load on a tower increases as tower height increases.

Control House Construction

On August 16, 1951, an explosion and fire occurred in the naphtha treating plant area of Humble's Baton Rouge refinery, the country's largest. Four tanks were destroyed, two severely damaged, three process units were damaged, pumphouses No. 2 and No. 3 were destroyed and damaged respectively. Windows in office and laboratory buildings were broken. Widespread glass breakage occurred—some four miles away. Twenty-seven railroad cars were damaged.

On Saturday July 31, 1965, a fire broke out in a plant at Baton Rouge, La. A control house was seriously damaged.

In January 1966, an explosion occurred in an ethylene unit of an integrated refinery in Germany. The one centralized control house 75 to 100 feet away from the unit was demolished.

Esso Research and Engineering concluded that where a central control house served major plants, that its construction should be considerably stronger than those previously built. Since the "brains" are housed here - that is, the computer and its related equipment - these delicate parts need full protection. Civil Defense planners feel this is an improvement in refinery construction and makes the plant less vulnerable to blasts such as would occur in a nuclear attack, hydrogen explosion, or damage from natural hazards.

Studies made by the Office of Civil Defense[74] indicate that control houses made of concrete blocks, brick with glass windows, and wood of conventional construction have roof collapse with pressure from 1 to 1-1/2 pounds pressure in excess of normal atmospheric pressure. As pointed out above, a refinery blast could easily create air compression that could exceed this pressure. Even an equilibrium type explosion or deflagration can exert this pressure on a control house located near the unit involved. A "black powder type" or a flammable gas "push" upon ignition (a normal explosion) can collapse the walls or blow out the windows of most control houses now commonly built in refineries. Such a house would not stand a chance in any first class bomb attack.

*Basic Concepts** - Bradford and Culbertson[54] discuss the problem of building stronger buildings. Their recommendation is that control houses be at least 100 feet away from any possible fire or explosion area and that the house be designed to withstand 3 psig static pressure and a wind load of 75 pounds per square foot and 1 psig negative pressure. They have designed a windowless single story, reinforced concrete structure which will be described in detail later.

The cost is only about 10% to 15% higher than that for a conventional building. This is considered a small added cost to protect high investment computerized equipment.

Bradford and Culbertson continue, "To construct buildings to withstand explosive overpressure, reinforced concrete or structural steel is used. Windows which fail at less than 3 psig overpressure cannot be employed. Construction costs to provide overpressure protection for two story buildings become prohibitive. Properly reinforced concrete for both walls and roofs will deflect under the influence of overpressure and will resist very high loads with light to moderate damage.

"Considerable testing also has been done at the Picatinny Arsenal in the design of structures to resist explosive blast effects. They have concluded that increased steel reinforcing in concrete greatly increases the resistance to peak overpressure and impulsive loads. Some designs have demonstrated failure points up to 25 times that of static design pressures.

"By use of elastic and plastic analysis, our engineers estimate that a building designed for 3 psig static pressure will resist a diffraction overpressure of 15 psig and reflected overpressure of up to 45 psig with light to moderate structural damage.

"With this in mind we have concluded that a concrete structure with proper steel reinforcing designed for 3 psig static pressure will resist the space explosions which can occur in plants with acceptable light to moderate structural damage. It is estimated that the cost of this explosion resistant design in most locations is no more than 15% over a conventional building, excluding contents value."

The question is asked,—where is special protection warranted? "In the Esso experience, there have been only a few instances of extensive control house damage in the last 15 years. Thus, considering the many control houses in the various plants, the probability of such damage is very low. Justification of the added cost of overpressure protection becomes somewhat marginal when considering only possible reduction in damage to the building and its contents. But the recent German incident did emphasize a matter of more substantial concern.

"The ethylene plant explosion and fire severely damaged those facilities, particularly the compressors. It took almost nine months to get that unit back into operation. In addition, the remainder of the plant could not be operated for about two months. Much of this delay resulted from loss of the centralized control house in the explosion and the need to install local instrumentation at each unit in order to operate them. Thus, the damage to the control house was a key factor leading to extended downtimes of a majority of the plant.

"In the past, with individual unit control houses, severe damage to those buildings would not in itself have shut down the entire refinery. Here a large area explosion would do significant damage to other equipment in the unit as well as the control house. Overall unit downtimes would be tied to repair of damage to all the equipment and not just the

* This discussion is given here to show what some companies are doing. Most control houses are not as strongly built. Where glass panels face the unit, a blast can often cause glass to fly into control equipment.

control house. The remainder of the units outside the explosion area could be operated by adjustments in product slates or importation of feed stocks.

"In many of the larger and more complex plants, numerous nonintegrated units can now be tied to one control center. It is possible that the control house can be damaged by an explosion in one unit that does not involve the other units. Thus, the downtime of the entire plant could depend on the rebuilding of the control house or possibly installation of substitute instrumentation. The business losses of complete plant shutdown could be extremely high in major plants of this type. It could represent an unacceptable possibility even though the chance of occurrence is low. The small differential cost to accomplish overpressure design leaves no doubt to Esso Engineering that protection should be included in such new plants.

"This becomes a much more difficult problem for existing control houses where the cost of rebuilding to provide overpressure protection can be substantial. No overall conclusion can be drawn that will be applicable for all plants and a specific risk analysis must be made for each specific location. We believe the prime factor for evaluation should be the business losses that could result due to the loss of the control center and consequent inability to operate sections of the plant outside the explosion area. Location of the control house and potentials for large vapor releases in this area are also important considerations.

"With highly integrated processes, damage to the control house only would occur in conjunction with significant other equipment damage. Thus, repair of the control house would not be the key to overall downtime for the plant. In these centralized control centers, there could be a high concentration of investment. In some instances overpressure protection may be warranted for the specific location if the actual incremental cost for the protection is small relative to the total investment in the building.

"In light hazard operations, such as fertilizer plants, we have not recommended any special building design for overpressure. This is based on the low possibility that a large area flammable vapor accumulation can develop.

"We recommend that centralized control houses in major refineries or petrochemical plants have at least 100 feet clearance from equipment handling flammables. This is recommended to minimize the chances of flammable vapors, under large release conditions, being drawn into the building and resulting in an internal explosion. Also, such separation minimizes the potential of missile damage in case of equipment or vessel failure. As spacing increases between control houses and potential release sources, the chances of damage to the building decrease. For one location, the centralized control house was to be located over 200 ft. from operating equipment. There was little chance of wide area vapor accumulation due to a normal wind condition. In this instance, no special overpressure protection was deemed warranted."

Warren[1] discusses the reasons for the blast resistant control houses and how such can be economically built. Portions of his paper are reproduced here so as to give this practical plan as much distribution as possible.

"Baytown Management feels that control center buildings which will house instruments and controls for several process units should be designed to withstand refinery-type hydrocarbon explosions for the following reasons:

1. Protect the control equipment and computer for several process units located in one building in case of a major occurrence on any one unit.
2. In case of explosion and/or fire on one unit, the control house operator should feel safe enough to remain at his post and perform his required duties during the emergency.
3. Provide a 'haven or refuge' for operators assigned to the units in case of a major occurrence.
4. Preserve records of events preceding any major occurrence.

"In addition to control center buildings, other refinery buildings such as laboratories should be designed with some degree of explosion resistance depending on their location, purpose, number of personnel, and other considerations."

In developing a design criteria, he states, "The first control center constructed at Baytown for multiunit controls and a supervisory computer is designated 'Fuels Control Center'. Presently, it houses control equipment for Baytown's new hydrocracking unit, which started up in April 1967. By the end of 1967, it will contain the controls for Fluid Catalyst Cracking Unit No. 3. Other units are planned for operation from the same building.

Design Criteria - "The design criteria were developed by comparing the known forces exerted by nuclear explosions of varying intensities with actual hydrocarbon explosions that have occurred. The damages resulting from some hydrocarbon explosions and the approximate amount of hydrocarbon involved are documented. By studying the available information and talking with recognized authorities in the field of explosions around the country, reasonable correlations were obtained between the amount of hydrocarbon material available and the resulting damage suffered by buildings at varying distances from specific explosions. It is recognized that hydrocarbon and nuclear explosions differ and that the force of a hydrocarbon explosion is affected by the amount of confinement, wind velocity, and many other factors.

"Another complicating factor is that published information showing the resistance of different types of structures and different building materials to damage by overpressure caused by explosions is sometimes contradictory.

"The effect of explosions on structures is extremely complex. An explosion produces a radial shock front that travels at high speed, plus an expansion of the air that travels behind it. When the shock front hits an enclosed structure such as a building, it raises the external pressure on all surfaces as it passes. Because this takes place quickly, the pressure, which is called overpressure, can be assumed as uniform over all the structures, and the little translation force is caused. Reflection of this shock front from the structure raises the peak value. After the positive phase of the shock front has passed, a suction front, lower in intensity, occurs. The expansion of air causes a high wind to impinge against one side of a structure causing a translational effect on the entire structure. This differs from the shock effect in that it occurs over a longer period of time. The resulting pressure is called dynamic pressure. Response of the structure to short time or explosion loads is related to the natural fre-

quency of vibration of its component parts acting individually or collectively. Because of this, overpressures of greater intensity and short-time duration produce the same effects as those of lower intensity acting over a larger period of time, the relative period of time being with respect to the natural period of the system being considered.

"The design criteria developed as a result of the above are contained in an engineering standard which is summarized as follows:[78]"

"1. Buildings shall be designed to be shock resistant if any one of the following conditions applies:

a. They are designated control centers.

b. They are specifically designated by the basic equipment and/or the Refinery Safe Operations Committee to be shock resistant.

2. The design criteria for shock-resistant control center buildings are:

a. Overpressure load shall be assumed to be three pounds per square inch static pressure on all enclosed structures, acting on all exterior surfaces of such structures.

b. A negative of suction overpressure load of one pound per square inch static pressure shall be applied to the exterior surfaces of all enclosed structures, in addition to the above, and considered separately.

c. A wind load of 75 pounds per square foot on flat surfaces shall be applied to the structure.

d. Dead loads, if any, shall be combined with the above.

"In preparing the standard, no attempt was made to match the force of any particular explosion. The characteristics of a nuclear explosion are known; the characteristics of hydrocarbon explosions are not well documented. The standard energy level related to tons of TNT does not include any measure of the amount of force due to overpressure, which is caused by the rapidity of detonation of the explosion. Since the overpressure is the greater force and the major uncertainty, any attempt at directly comparing the effects of different explosions could be quite misleading. Missiles are sometimes created during an explosion. Any pressure vessel failure or piping failure could be cause for disintegration of the container, and portions of the container could travel at high speeds which could destroy portions of buildings or structures. It is therefore felt that any attempt to correlate a possible explosion with the measure of protection provided is in error because of the uncertainty of the variables. It is believed that the best approach is to provide at reasonable cost some protection against a reasonably expected blast force. This extra cost can be viewed as insurance, and it can be evaluated by engineering judgment in terms of the possible hazards."

Construction Details - In dealing with fuel control center buildings, Warren[1] states, "Design and construction details of Baytown's Fuels Control Center building are used to illustrate how a building can be constructed to withstand the blast forces included in the proposed standard.

"Figures 57 and 58 show the control house damaged by a space explosion.

---

78 Humble Oil and Refining Co. "Buildings Designed for Shock Resistance" Baytown Engineering Standard No. 15.01-3P

"Figure 59 is a picture of the front of the building. It is rectangular-shaped with dimensions of approximately 52 feet by 73 feet and outer walls 15 feet high. It was constructed using precast concrete wall panels, poured-in-place concrete columns between the wall sections, steel joist roof framing with corrugated steel deck, and structural concrete roof slab.

"A section of a wall, floor slab, and roof slab is shown in Figure 60. In addition to designing the walls, roof supports, and foundations (Figure 60) with sufficient strength to withstand the design forces, it was of utmost importance that connection points between the different components were designed and installed properly. The walls were connected to the floor slab by welding together steel angles and plates that had been precast into the concrete. The bar joists were welded to a steel plate in an offset at the top of the wall, and one row of steel from the wall extended into the concrete of the roof slab. The corrugated metal deck was welded to the bar joists.

"Several pictures that were made during building construction are included to illustrate additional connection methods and details.

"Figure 61 is an overhead view of the floor slab and beams during the pouring of concrete. Note the reinforcing steel extending from each drilled footing that was later connected to the steel in each poured-in-place concrete column. Figure 62 is a close-up of one corner showing the reinforcing steel and the steel angles in place that were welded to the steel in the precast walls. The steel at the top of one of the precast wall panels is shown in Figure 63.

"The precast wall sections were hauled by truck to the building site, unloaded, set in place, and supported as shown in Figure 64. The steel joists were installed (Figure 65), the corrugated steel placed, and the columns and roof slab poured. Figure 66 shows the building during this phase of construction. When the installation of the outside door frames and doors were completed, all the structural requirements for making the building shock resistant had been fulfilled. Finishing work such as inside walls, floors, ceilings, etc., was performed the same as for a conventional building. The interior of the control room facing the entrance door and hallway is shown in Figure 67. The corner of the room shown at right is part of the computer room. The operator's console is in the room."

In discussing the added cost for shock resistance, he states, "Any decision to spend more money than the minimum required to 'get the job done' on a project is largely influenced by economics, safety, or a combination of both. In developing the design criteria for blast-resistant buildings, every attempt was made to provide reasonable protection of reasonable cost. For the Fuels Control Center, cost estimates were made for a building with conventional framing and for one designed to withstand three-psi static overpressure. The difference between the cost of the two was estimated at approximately $2.50 per square foot of floor slab area or $9,250 for the 3,700-square foot building. This was between 10% and 15% of the estimated cost of the building and was considered to be reasonable cost for the added protection. The added cost of providing shock resistance was approved by Baytown Management on the above basis. The

Figure 57. A Plant Control Room After a Detonation

Figure 58. Interior—A Plant Control Room After Detonation

Figure 59. Fuels Control Center

Source; Humble Oil and Refinery Company

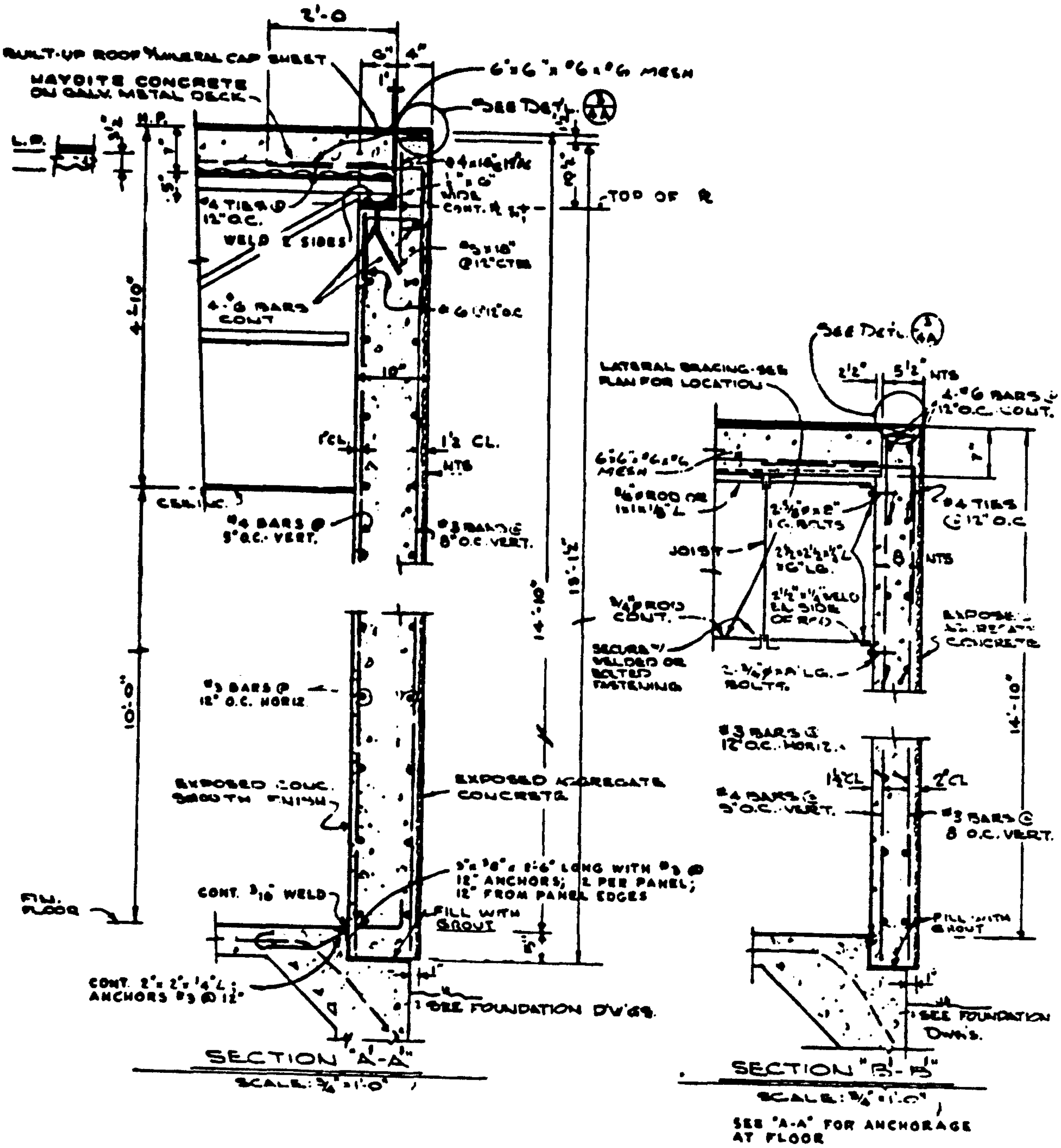


Figure 60. Wall Section and Connection Detail

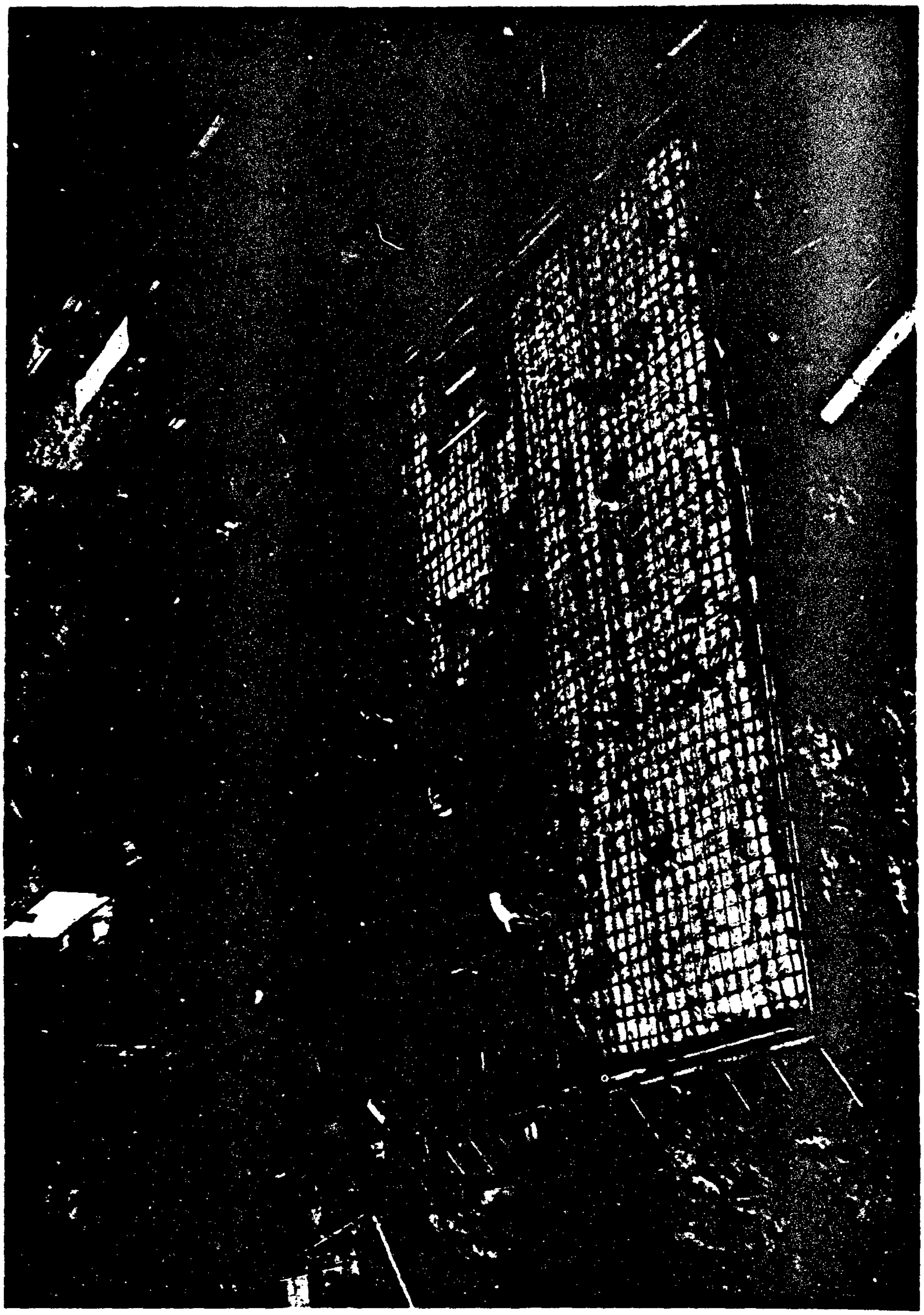


Figure 61. Placing Concrete for Floor Slab and Beams

Source: Humble Oil and Refinery Company

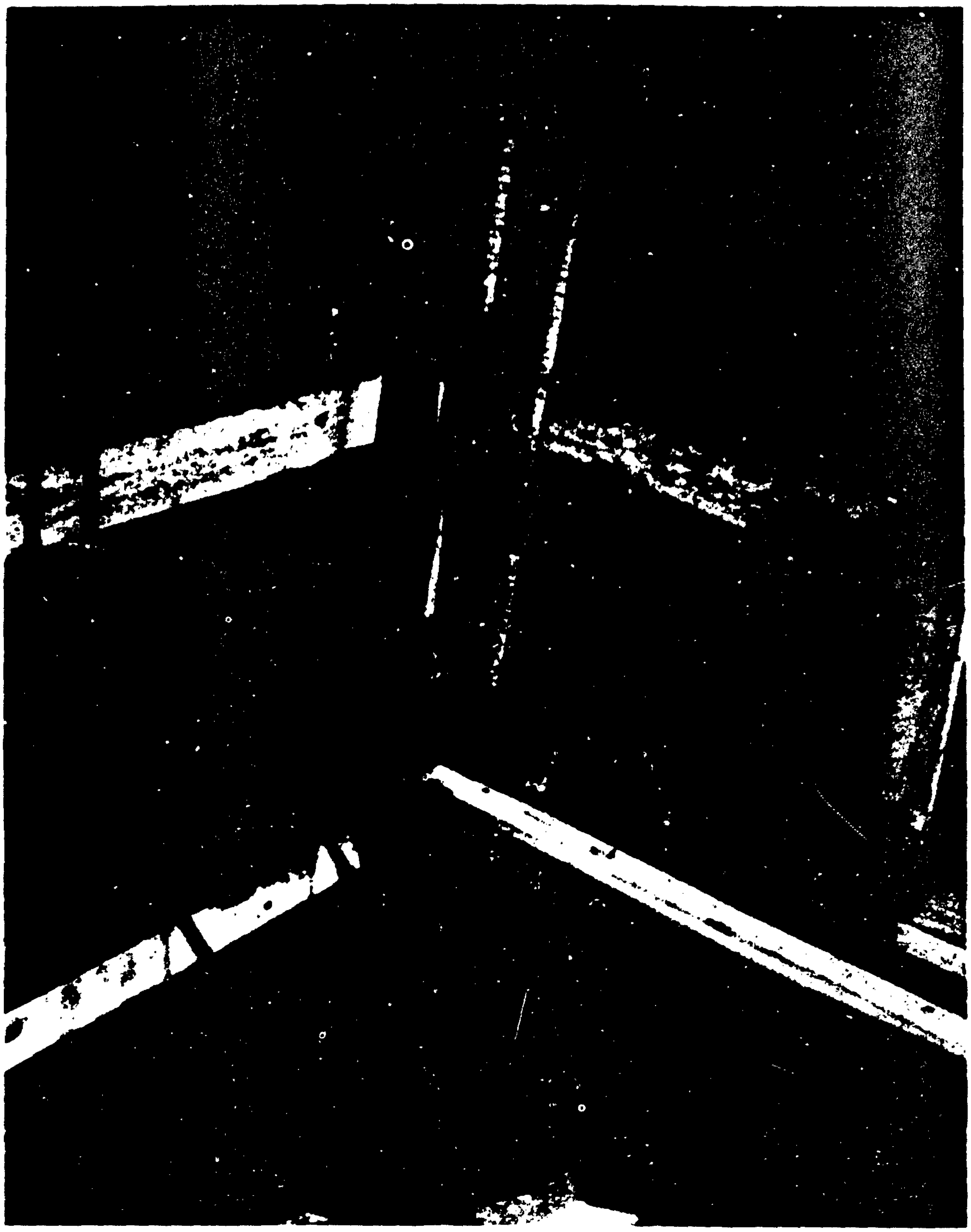


Figure 62. Reinforcing Steel for Beams, Slab, and Corner Column

Source: Humble Oil and Refinery Company

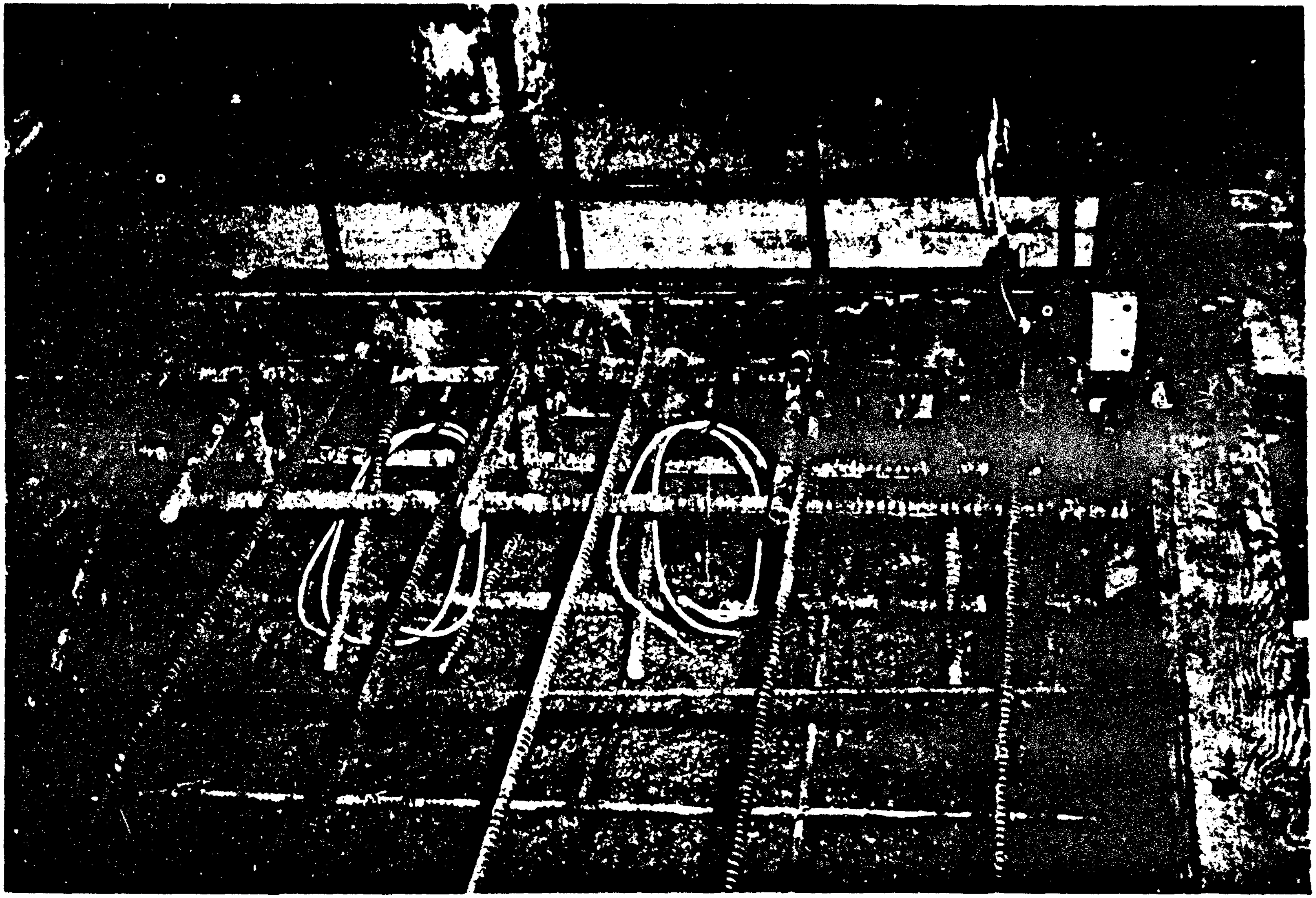


Figure 63. Reinforcing Steel at Top of Precast Wall Panels

Source; Humble Oil and Refinery Company

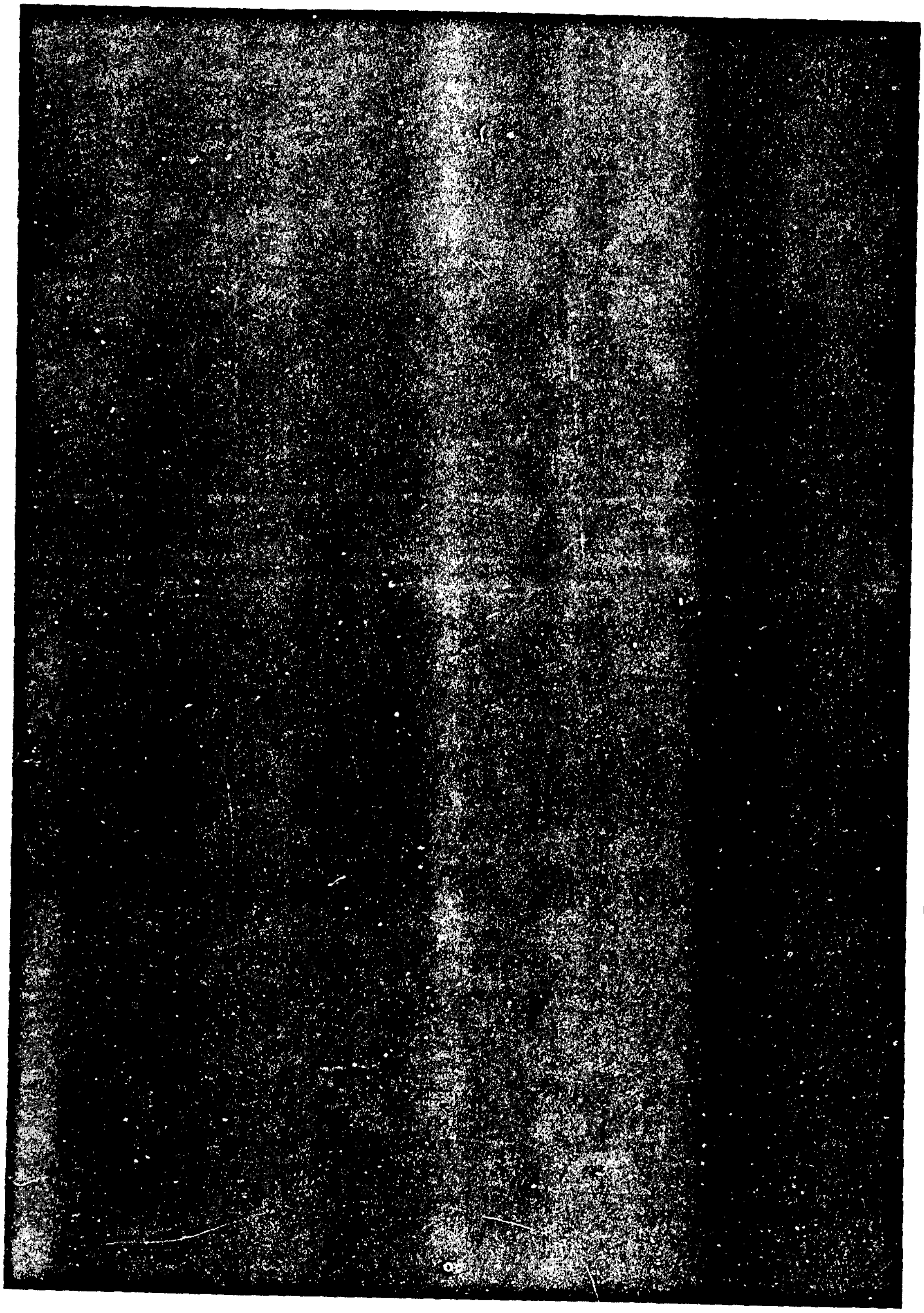


Figure 64. Temporary Supports for Precast Wall Panels

Source: Humble Oil and Refinery Company

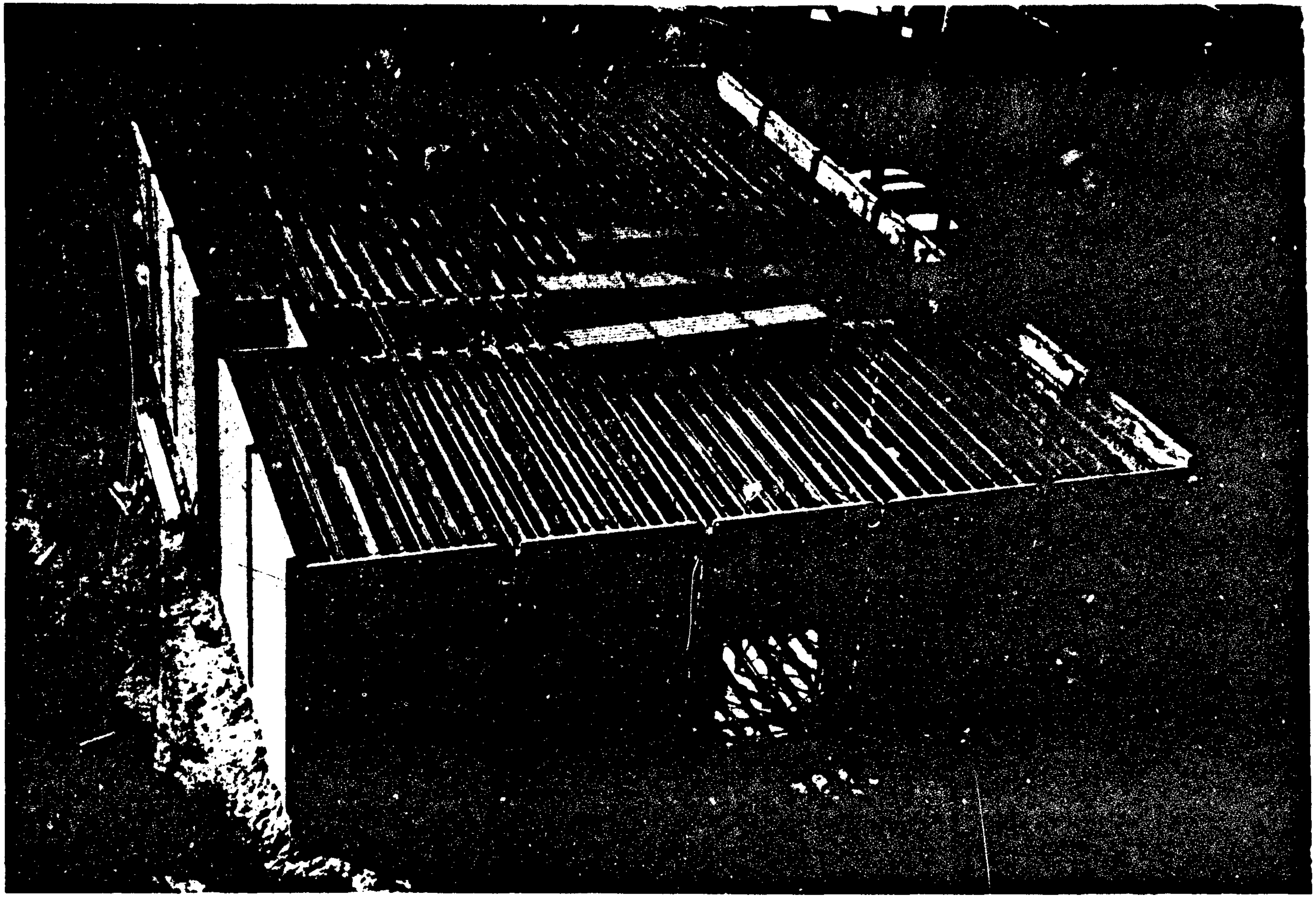


Figure 65. Roof Joists and Steel Decking

Source; Humble Oil and Refinery Company

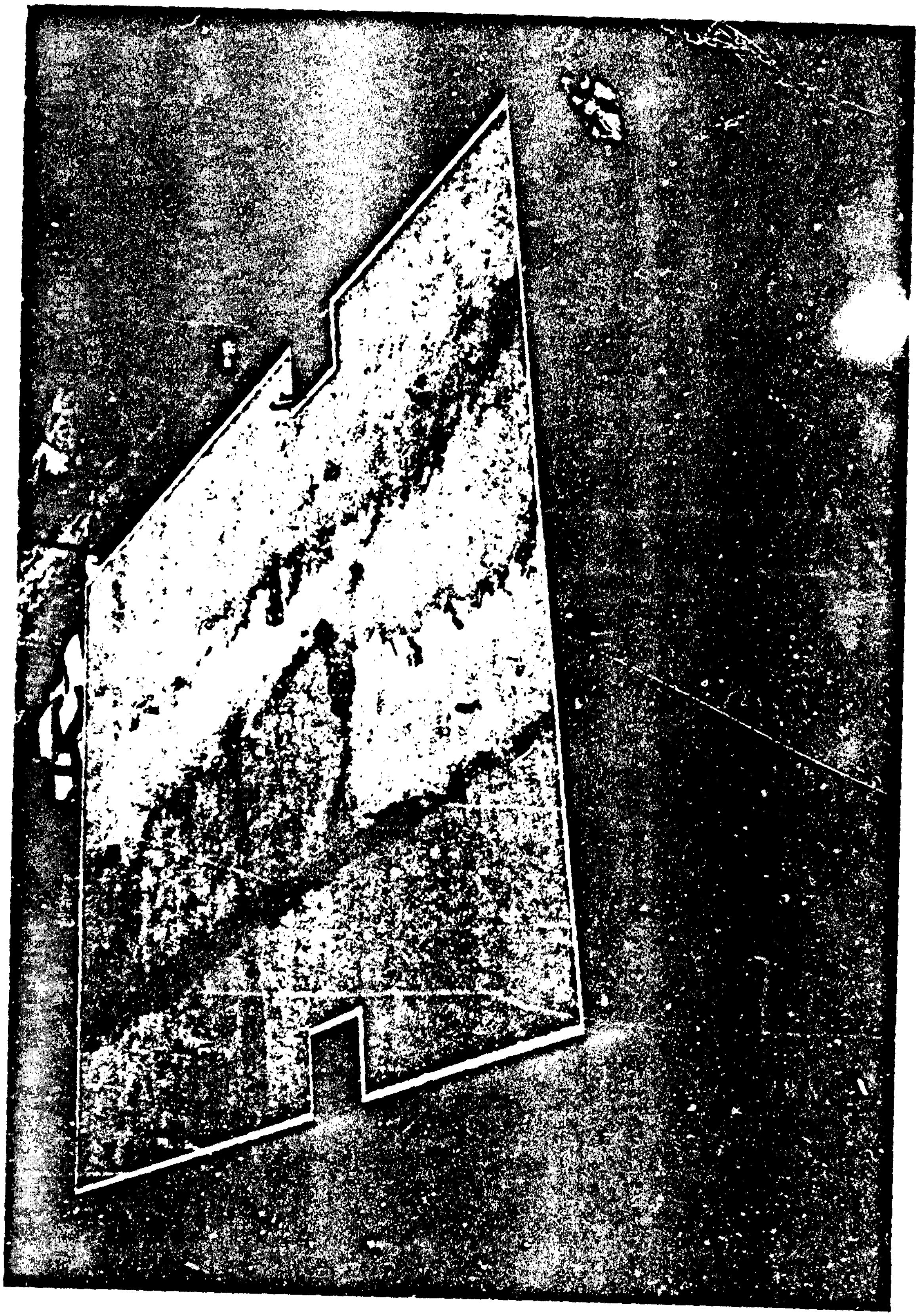


Figure 66. Completed Shock-Resistant Structure Less Doors, Roof, and Finish Work

Source: Humble Oil and Refinery Company

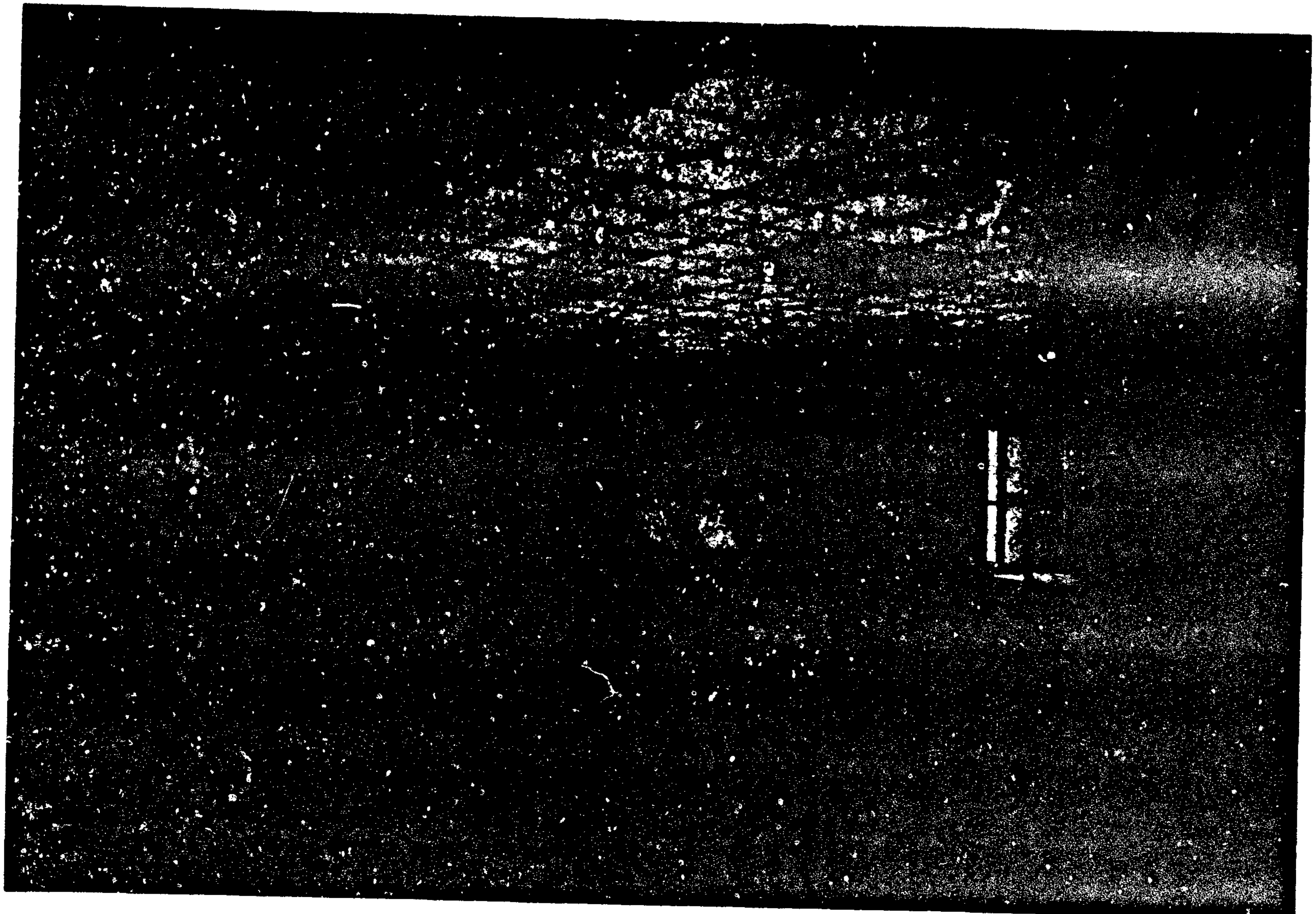


Figure 67. Control Room Before Installation of Panelboards

Source; Humble Oil and Refinery Company

actual cost of the completed building excluding the cost of the control panels or process instruments was approximately $23 per square foot which is a very low cost for even a conventional building. It is assumed that the objective of providing reasonable additional protection at reasonable cost has been accomplished."

Warren concludes, "Baytown's experiences with two recently completed control centers prove that buildings can be designed using standard materials and conventional construction methods to provide reasonable protection against explosions at reasonable cost. The cost of a blast-resistant building is 10% to 15% more than the cost of a conventional refinery control house building. It is Baytown Management's opinion that this additional cost is justified."

Underground Structures

The Esso Research and Engineering Plans as implemented at Baytown and elsewhere should serve well. It is a great stride forward toward strengthening weak but vital components of a refinery complex. There is one additional thought that, if added to the Esso plans, should substantially reduce control house damage due to detonations.

Burial of the structure discussed or mounding them, covering the roof area with two to four feet of packed dirt and a slope of at least 1 to 4 along the sides, should greatly improve the blast-resistant qualities of the structure. Few refinery blasts could touch it. There is a plus value added to this plan. By adding mass - that is, weight of material over the roof of a well-built structure, one adds a nuclear fallout protection factor to persons within the building. The amount of protection from exposure to fallout - i.e. radioactive dust and particles landing on a roof area of a building as a result of a nuclear discharge, can be calculated. As roof weight per cubic foot and distance below the roof increases, the protection to personnel increases. By adding this protection factor and perhaps by adding eating and sleeping accommodations, a fallout shelter and protected operating headquarters is made. There are also other types of suitable construction. *Drifting fallout could make working in a refinery impossible even though the plant is unharmed by the explosion. Much can be done to keep things moving during such times if a protected environment is provided for the operators.*

Currently, few if any refineries or petrochemical operations have this personnel protection capability. *Civil Defense planning requires more to be done in this field.* There are many well-stocked buildings displaying the Civil Defense symbol that offer sanctuary in time of nuclear attack. Presently there are stocked places for over 100 million people. In so many cases, however, the buildings offering this protection are not on working premises. *The current need is for protected working facilities.*

Many publications are available by the Office of Civil Defense giving detailed plans of construction of practically every type of community, industrial, and home structure capable of offering fallout and blast protection. *Any modern construction that does not encompass such plans considering world conditions is obsolete before its foundation is laid.*

The Industrial National Bank of Providence, Rhode Island (as have others) built its computer center to withstand 20 psi overpressure. This is one of the best known to date. This structure was nominated as one of the seven outstanding Civil Engineering Achievements in 1962 by the American Society of Civil Engineers. It shared honors with Dulles International Airport, George Washington Bridge, Trans-Sierra Highway, and others.

The structure was designed to take an airburst from a 5 megaton nuclear bomb. Probability of a direct hit was calculated as being one in a thousand. The building is completely self-contained with its own wells, power generator, air purification equipment, computer center, storage vault, conference rooms, lounge, kitchen, and bath and toilet facilities. The building is 90 by 125 feet with a gross height of 25 feet, covered by 2 feet of dirt. By burial of the structure, wind (drag forces) needs no further consideration. The building is built of a "plastic" design,[79] a design which with the proper selection of load factors, has kept "permanent deformation substantially below those ordinarily acceptable in shelter structures where much of the energy-absorbing plastic resistance is utilized.

"The roof structure is a two-way slab system of bays 20 by 25 feet. The slab itself is 22 inches deep and is heavily reinforced with No. 7 bars in the top and bottom faces in each direction. The supporting beams are 48 inches wide and have a total stem depth of 38 inches, including the slab. The beams are reinforced with two rows of No. 9 bars in each of the tension and compression faces.

"At the exterior walls, the roof beams frame into external buttresses founded on large, heavily reinforced spread footings. The exterior wall panels between the buttresses are 20 inches thick, heavily reinforced by No. 7 bars in both faces. The interior columns are 30 inches square and are reinforced by No. 8 bars. They are likewise founded on large spread footings.

"To dampen the effects of air-induced ground shock and to eliminate any possibility of dampness forming on the finished concrete floor surface, a unique floating slab-on-grade section was devised. It consists, from top to bottom, of the following elements.

1. A concrete floor slab 8 inches thick.
2. A plastic vapor barrier.
3. Rigid insulation board 2 inches thick.
4. A neoprene membrane 1/16 inches thick.
5. A concrete leveling slab 3 inches thick.
6. A polyethylene laminated sealing membrane.

"The 1/16-inch neoprene membrane is bonded to waterstops of the same material that are embedded in each footing. These same waterstops along the perimeter walls are bonded to neoprene sheets that completely cover all exterior wall, buttress and roof surfaces. Thus, the Computer

---

79 Noyes and Co., Inc. "Hardened Building Withstands Overpressure of 20 psi" A news release for Industrial National Bank, Providence, R. I. July 7, 1963

Center is completely enclosed in a flexible waterproof neoprene covering that will remain effective under all conceivable normal and attack conditions that may be imposed.

"To protect the occupants and equipment against overpressure, all conduit and pipe entrances into the structure pass through special pressure-tight sleeves. All air intakes, exhausts and vents are protected by pressure-actuated blast valves that are extremely fast closing. Special high-temperature-resistant blast valves were provided for the diesel-engine exhausts located in the emergency power room. To solve the difficult problem of maintaining continuous security against blast overpressure, as related to the main entrance, electrically interlocked double blast doors were used, employing the air-lock principle.

"Design criteria for the effects of a nuclear blast imposed severe requirements on the shock resistant capabilities of all mechanical, electrical and utility systems. All major and critical units had to be evaluated to establish basic fragility levels. Appropriate shock mountings were provided to counteract the effects of the accelerations and displacements established by the shock spectrum.

"Because the site is underground, special attention was directed towards such physiological and psychological considerations as lighting intensities, interior color selections, acoustics and environmental temperature and humidity control. Special architectural details were developed to anchor many otherwise common interior installations. Acrylic plastic was used instead of glass throughout to reduce possible injury and damage from flying debris during an attack. All pipe, conduit, and duct systems were provided with special supports and flexible connections to either absorb or resist blast effects.

"All principal electrical and mechanical equipment and associated distribution systems were designed employing a duality of components and services to preclude total loss of a vital service in the event of unpredictable damage.

"To meet the requirements of emergency shelter operations, the Center will be supplied with cots, bedding, emergency food supplies, medical supplies, radios and special communications and radiological monitoring equipment."

There are similar installations, some of which are in old mines and caves. Many of these underground facilities are as functional as any modern office, yet living accomodations for key personnel and their families are provided so that groups could efficiently function for at least a month without seeing the sun. To date, most blast and fallout protection facilities are often some distance away from the daily area of normal operation. Also, banks and company headquarters have for the most part received greatest attention. What is a *Must in Industry* is *to have in-plant protected facilities so that the plant can be operated under fallout conditions.*

The use of control houses as equipment and personnel protection is becoming more and more popular. "Havens of Safety" certainly are needed. It is probable that several other critical areas of a plant might need "bunker like" protection against fires. Certainly we need to provide in-plant protection for operators when considering possible enemy attack and war damage. *Such work must be done now, for there will be no time to do much in case of a nuclear attack.* If a plant cannot be operated remotely from a completely protected structure, that plant is not prepared to withstand even attack of a conventional type.

The refinery industry has a long way to go before building underground will be given much serious consideration. It is suggested that much can be learned from the German bunker construction program and their underground operations. Some reference was made to this in the discussion of fires.

War planning related to the petroleum field requires a greater thought of using underground structures than has been done. This was pointed out by the Office of Engineers in their pamphlet "Underground Plants for Industry."[80]

"There is little doubt in anyone's mind that American Industry may become a target for enemy bombs, since it is an acknowledged fact that American Industrial Production tipped the scales toward victory in both World War I and World War II.

"It has also been established that underground sites provide the maximum possible protection against atomic explosions.

"There were no successful destructive attacks on German underground installations, in spite of positive knowledge of their locations and unrelenting precision bombing by American and Allied Air Power. . . .

"The placing of a vital segment of our industry's underground *now* would avoid one of the most costly mistakes made by the German Government when higher authority overruled the recommendations of their engineers.

"One can understand this error by German leaders in 1940. It was the year of Dunkirk, with France and the low countries overrun, Norway and Denmark occupied, their air and other defenses seemingly invincible. In view of the type of bombing they anticipated, their too-little and too-late attempt to put their war machine underground is not surprising.

"Learning from experience, underground construction should be planned now, even if activation of the plans is made contingent upon expansion, or D-day, or the awakening that the emergency is upon us.

"Planning as well as construction takes time, and, what is more important, planning precedes the laying of corner stones.

"Some of our more successful industries appoint a Vice-President-in-Charge-of-Tomorrow. By any other name, such a man should apply our knowledge of Atomic Power to planning how his plant can meet the threat of destruction with plans for survival and victory, in case of war.

"The destruction of a single vital link in the chain of manufacturing can break the entire production of a plant with untold far-reaching effects.

"Perhaps the minimum immediate necessity in one plant will be to start planning, in the next plant to design an underground pilot plant and in the next the construction of a complete duplication of above-ground activities in another underground protected area.

---

80 U. S. Department of Defense "Underground Plants for Industry-Department of the Army Office of Engineers—AGO 1018313—Reprinted Jan. 1962 p. 5.

"It is practically impossible to establish any overall indices of costs for reliable comparison of normal (aboveground) construction with modifying an existing underground area or constructing an entirely new underground site. Cost depends on the analysis of a specific site which is to be developed for a specific purpose. Sound comparisons involve the evaluation of scores of variables operating within their own framework.

"However, three plants (Precision Manufacturing, Chemical Processing, and Storage) were studied and a few conclusions were drawn regarding their costs of construction, their operation and maintenance.

"a. Chemical Plant. It was found that underground construction of a chemical plant may cost about a third more, if established in an existing mine and as much as 60 percent more if developed in a newly excavated site. However, operation and maintenance costs increase only 4 to 6 percent and this rise is due largely to the need for removing fumes and heat.

"The increased cost of construction results largely from the need to provide space for yard area and a tank farm, which aboveground are not usually included under the roof of the plant.

"b. Precision Manufacturing Plant. A light manufacturing plant might cost as much as 20 percent more if installed in an existing mine or underground area, and nearly half again the cost of an aboveground plant if built into an especially excavated site. The increase in construction cost is due largely to the need for accommodating air-conditioning and ventilating equipment.

"The operating and maintenance costs of a light manufacturing plant vary only 2 to 3 percent from a conventional aboveground plant.

"c. Storage or Warehouse. Not surprising is the finding that storage space is less costly underground (in an existing mine for instance) than when built above ground, both from the standpoint of operation and maintenance.

"Furthermore, an underground storage area can be built into a new site at a cost of only about 12 percent higher than a conventional aboveground structure.

"It need hardly be pointed out that an underground storage area can be easily modified to house a light manufacturing plant.

"d. Cost Comparisons.* Average overall unit costs (square foot of underground floor area) were approximated at—

$13.40 for light manufacturing
15.00 for chemical processing
6.35 for active storage

"The most efficient underground plant is a large industrial complex (group of related units).

"Costs of protection against the effects of an atomic explosion (other than a direct hit) will of course be much lower than complete protection.

"Approximately 60 percent of American industry lies in a quadrangle extending from Boston to Kansas City and about two-thirds of existing mine sites suitable for installing an underground plant also lies within this area.

"Not only are most of the existing mines in the United States of America adjacent to industry, but investigation of their geological formations indicates that limestone, granite and sandstone, which are best for underground plants, are plentiful. However, an industry can be installed underground in virtually all existing formations.

"The study of the need for underground plants must of course take into account the possibility of dispersion, camouflage, duplication of facilities, stock-piling, and transportation.

"However, when all is said and done, nothing affords better protection (of production and product on personnel) than a plant located underground in a sound rock formation. A minimum of 50 feet of overhead cover will provide a reasonable degree of protection against all known weapons.

"Experience in Germany, Sweden, Italy and other foreign countries indicates that workers accept underground working conditions as normal, especially if the walls and ceiling resemble windowless factories, bank vaults and subways.

"In fact, the opportunity to work underground, reasonably safe from atomic blast, radiation and fallout might prove an inducement to apply for employment in such an installation."

It is evident that if international tensions continue to tighten that some tangible move will be required of government and industry to protect our refinery processes. In the United States, it is entirely foreign in refinery and petrochemical unit design considerations to think of anything but above-ground operations except possible for product storage. If we are to survive and operate even in conditions of conventional warfare, the protection of our refineries is paramount. As refineries now exist, it is difficult to think of any installation more vulnerable to bombing. Camouflage and the use by the Germans of underground protection were strong factors contributing to the ability to continue to supply their machines of war with liquid fuel. If only vital parts of a refinery were given underground protection now, that in itself would be a start in the direction of ultimate need. The danger of close confinement of units is recognized. This problem can be solved by using separate compartment type construction for various units.

Underground Storage - Old mines are popularly used for record storage or corporation headquarters in time of warfare. The storage of LPG (liquifiable petroleum gases) and other products is becoming more popular. One notable example is in Michigan where an underlying salt zone is dissolved out to make a storage cavern. In some areas actual mining out of a storage cavern was found desirable.

Many fires of historic note have resulted from projectiles flying through the air from a detonation and into the tank farm and terminal areas. Protected crude and product storage could have prevented the extensive damage done by some of the accidents discussed above.

Figure 68 shows a series of storage tank designs used in Germany (Figure 68) during World War II. It is possible as storage problems become greater that one should reconsider some of these tank designs which have been found to be

*1962 dollars

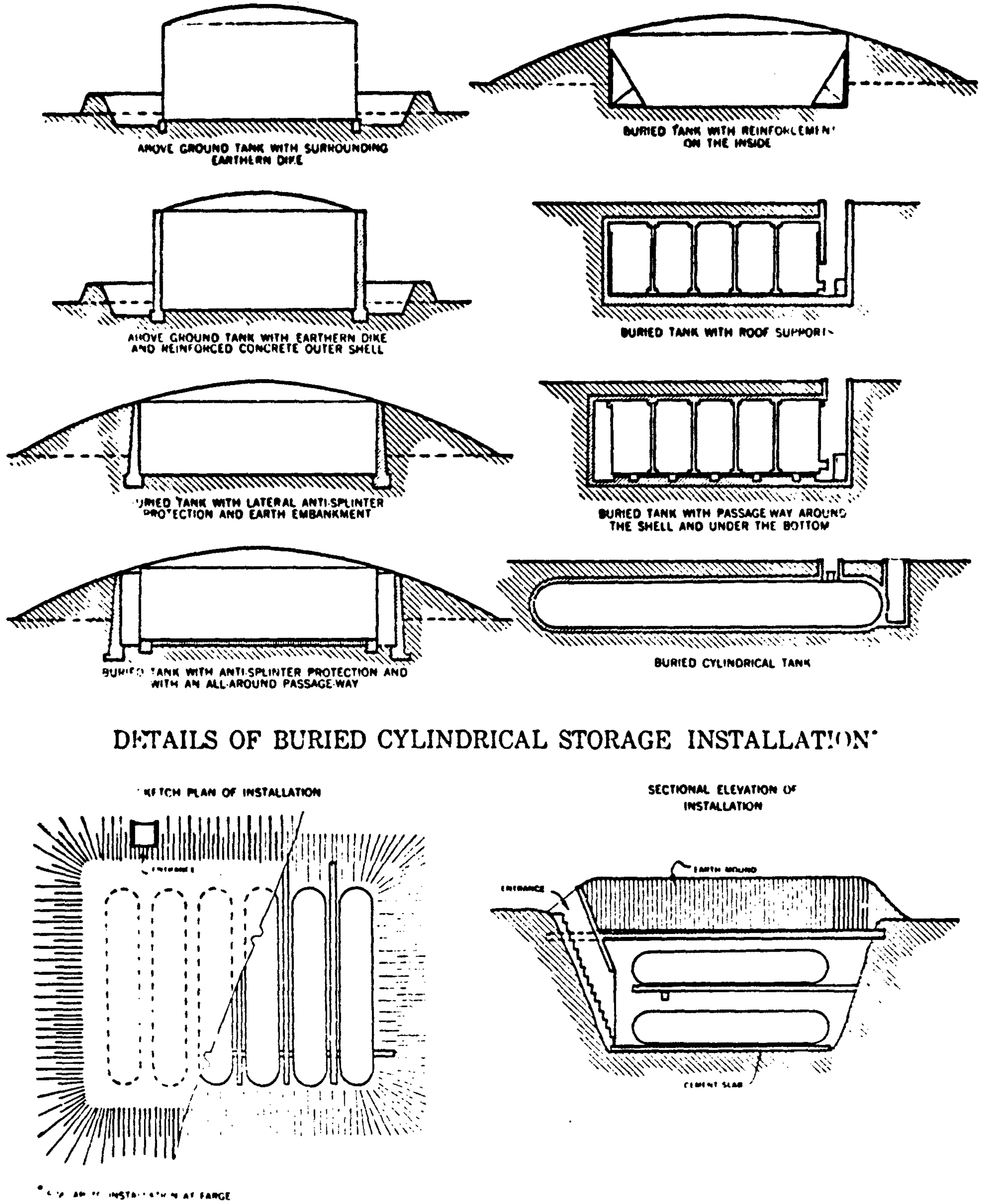


Figure 68. Types of German Storage Tanks

satisfactory in the past. The exact design followed will of course vary depending on the intended use as well as the geographical and ground conditions.

Round Structures

It is interesting to observe an area after a bomb drop or in-plant detonation. So often stacks, round vessels, and full tanks are relatively unharmed, where square or rectangular buildings are completely demolished. A comparison of figures 1 and 2 illustrates this point to a degree. Bombing in Japan was less effective on stacks and round objects than on rectangular structures.

While we are accustomed to building rectangular buildings, it could be possible that round buildings in some cases would be desirable, particularly, those subjected to blasts—refinery control houses and service buildings. Consider spherical shapes also.

A blast striking a rounded surface cannot build up much reflected pressure and, because of stream lining, the building's adjustment to this static load is more uniform than with a square or rectangular building.

Wind loading (dynamic forces) also becomes less on the side of the blast since the area of wind contact with a circle is less than that with a flat surface.

General Observations - Section I

Any loss prevention program, any consideration of plant design, any implementation of operation safety, anything done in a refinery complex to prevent fires and explosions, anything done to prevent losses created by natural occurrences, in-plant accidents, or persons causing intentional damage- all are contributing to the efforts of Civil Defense. A plant built and operated to withstand the many potential hazards is a plant better prepared to cope with operational problems related to warfare. Few plants are ready for such events, but it is essential to prepare now for such a possible catastrophe. When the time suddenly appears that extra durability in our sources of energy supply are needed, it is then too late to reinforce our installations for neither will there be sufficient time nor material to build in the extra protection that could have been incorporated in the original design.

Our refining capacity is concentrated in several areas of the country. Often nearby chemical and petrochemical plants add to the concentration of the liquid fuels and related industries. Any catastrophe, either natural or man-made, can destroy a large percentage of our refining capacity in a single event. From a strategic viewpoint, it would be wise to have smaller plants and refineries scattered throughout the nation near large cities of the interior.

Those refineries on tidewater can expect winds from hurricanes in excess of 200 miles per hour. Those located in the central plains area can expect winds from tornadoes to exceed 500 miles per hour.

As automation increases, so does it become important to increase "automatic remote-controlled" fire protection for there is a trend toward having fewer employees in the plant to handle emergencies.

Those plants operated by control houses located within or close to their respective units are increasing their risk susceptibility.

Those plants not providing blast-resistant control houses are in danger of experiencing a long downtime due to in-plant accidents.

Those plants along the west coast can expect a major earthquake equal or greater than that experienced in Alaska. The trend in building taller towers and buildings is neglecting the certainty that such will occur.

As refineries get larger and spacing between units becomes less, the risk of operation is increasing and the danger of a major loss is increasing.

Any operation that does not include provisions to protect the workers from fallout and provide remote control of units will be shut down during and after a nuclear blast. The thought is in the minds of some that to build a plant without making such provisions, considering the world conditions, is to build an obsolete plant.

A control house and other buildings of the plant need to be constructed so as to give a protection factor (explained in Section II) of at least 40.

Strength and accident prevention considerations applied to a refining facility should save on insurance rates and at the same time make the plant less vulnerable to natural forces, in-plant accidents, and to enemy action.

Building underground where possible offers the greatest protection for personnel, equipment and supplies.

Section II

The Industry Under Conditions of National Emergency

Figure 69. Atomic Blast - The Base Surge, the Column and the Cloud Are Clearly Visible (A Rocket Was Shot Through the Cloud)

Source: U.S.A.E.C.

Chapter VIII

NATURE OF NUCLEAR WEAPONS

Warning Time

It is the sincere hope of the people of the United States and their elected representatives that there will be no more wars. Several wars have been fought as the "last war", and because of the knowledge of the destruction potential of a modern war, and last global war might well have been fought. Certainly the existing nuclear powers will not be irresponsible enough to start a confrontation, for they realize no one could benefit from such action. Both sides would have great losses. But, considering that there is only a thin line between fanaticism and mania, it is possible that a demoniac leader of some nuclear power in time will evolve who, in a fit of anger or because of national frustation, will "push the button", bringing widespread destruction and death to millions!

One can conceive of a situation, however, where nations could reach a point of intolerable provocation. Such could be created by starving people as population continues to explode, by nationalism developed to a point of insanity, or by a complete breakdown in communication between governments created by widely diverse ideology. The relatively small-scale wars constantly breaking out further emphasize this possibility. Many nations possess or soon will have the capability of creating a nuclear war, and as long as such a potential exists, it is imperative that nations work and plan to reduce damage to themselves and their industries from such an occurence.

A nuclear blast could come as a result of the escalation of a localized conflict or by accident. If so, a deterioration of international negotiations would be observed from day to day and industry would then have some lead time and time for preparation. But, it is possible that no such warning will occur. With the Free Orbiting Ballistic Satelites (FOBS) and other types of weapons possibly circumnavigating the globe, a nuclear blast could be triggered by the "push of a button" accidentally or otherwise. In such a case there will be no warning! *Those industries that are ready have a chance at survival!*

What Can Be Expected

What would happen to this nation should a major power wage a nuclear war against us? We already have experienced the destruction wrought by detonations, by earthquakes, and by hurricanes and tornadoes. This relatively local destruction multiplied by some large number and covering many localities and many square miles of area could bring to view some idea of the multiplicity of problems which would be developed by a nuclear weapons.

If one can imagine the damage left by a hurricane travelling along shore around the Gulf of Mexico from New Orleans to Corpus Christi, doing widespread damage everywhere in its path comparable to that done by Carla or Camille and others, some appreciation could be given of the problems and complications that would have to be met and immediately solved after a nuclear blast in that area. Simultaneous damage would be visited on industries and communities and similar recovery needs generated. A series of nuclear attacks covering many industrialized areas would create simultaneously major recovery problems. The Office of Emergency Preparedness makes the following appraisal.[30]

As a result of various hazard studies, the attack presumed most probable at the present time lasts 48 hours and consists of 450 weapons representing a total yield of 2,300 megatons. Most of the weapons fall during the first hour. They are evenly divided between air and ground bursts directed at military, industrial and population centers. Ports and transportation centers are especially hard hit. While fallout is a serious problem, in general most parts of the country are accessible within two weeks. No major sections of the country are completely isolated due to fallout contamination. Fallout intensities at H + 1 hour in a few cases exceed 10,000 roentgens per hour. Many areas receive less than 100 roentgens per hour.

"Such a nuclear attack on the United States would reduce the population from 200 million to 145 million. During the first month, 31 million would need hospitalization. Deaths during the first year would further reduce the total population to 125 million giving a total decrease of 38%."

The nuclear attack is only one part of any war program. It is always possible for an enemy to place agents ashore for espionage and sabotage. Unfortunately there are citizens, some even with a surprising amount of education who would sell their birthright of freedom and be traitors to our country. Considering the exposure, the processes, and the relative ease with which great damage can be effected on refineries, natural gasoline plants and petrochemical units, enemy agents alone could create a national disaster.

Emergency Planning

It is therefore a present challenge to industry to assume that they are operating in wartime conditions, and to build and manage their plants with the full appreciation of the consequences of indifference and laxity. It behooves all management to make a good review of their operating conditions and situations and then correct the areas where strength and security are found wanting. Most companies have or are developing procedures for emergency operation. These plans need to be reviewed constantly to keep them updated, practical, and in complete accord with world conditions.

Further, it is important that these plans augment the national plan and those formulated by the individual states.

Couch,[81] Assistant Director for Industrial Participation of the Office of Civil Defense, in his discussion of survival plans, lists the following three broad categories of planning:

1. Protecting life and property
2. Preserving the corporate structure
3. Promoting community and national survival

Certainly no management can consider itself informed without having a working knowledge of the material presented in "The Effects of Nuclear Weapons" by Glasstone[12] for the Department of Defense,– "Strategy for Survival" by Martin and Latham,[83] and "Hearings on the Biological and Environmental Effects of Nuclear War" published by the Congress, the testimony therein having been received before a Subcommittee of the Joint Committee on Atomic Energy during 1959. The Office of Civil Defense has literally tons of literature on the subject including plans for buildings capable of providing protection in the home, in public buildings, and in industrial structures. *As mentioned several times before, no modern building is actually modern without built-in protection from nuclear blast.*

The Anatomy of a Nuclear Reaction

A conventional explosion from TNT or a detonation in a plant is a chemical reaction in which energy is released. Refiners are well aware of the results of an uncontrolled sudden reaction between hydrocarbons with oxygen, hydrogen or nitrogen in explosion. In such a detonation, there is no breakdown within the atom. Electrons from the reacting elements exchange places or combine to form new compounds during the explosion.

An atom, the smallest part of an element that can enter a chemical reaction, has a nucleus, a relatively heavy central core. Electrons, negative charges, orbit around each nucleus; they are very light by comparison to the nucleus. The mass or weight of the atom comes from the nucleus. The atom of a substance might appear quite like the solar system with the sun as a nucleus and the planets, electrons.

An atom is too small to be seen with even a powerful microscope. To get some relative concept of the relationship between the nucleus and its electrons, if the nucleus were the size of a baseball, its nearest electron would make an orbit around it larger than the perimeter of New York City.[82]

The electrons of the atom carry negative charges. Their number and pattern of orbit are determined by the size of the nucleus. The interlinking of electrons of various elements makes chemical compounds possible.

The nucleus of a particular atom is composed of protons carrying positive charges and neutrons which are neither positive nor negative; they are neutral. The number of protons is balanced by the electrons in orbit. The number of neutrons and protons in a nucleus determine the physical property of that material (atomic weight). The number of neutrons in relation to protons of an atom may vary. As elements increase in the atomic number, the more there are of neutrons in relation to protons. As an example, a lithium nucleus has 3 protons and 4 neutrons; uranium, 92 protons and 146 neutrons. An atom of any one element can change its number of neutrons without altering its chemical properties. See Figure 70.

The number of protons of an element determines its chemical properties (atomic number). For example, all material with only one proton is hydrogen. All material with eight protons is oxygen; ninety-two, uranium. If the number of protons of a material is changed, a different element is formed. The larger the number of protons or positive charges, the larger and heavier the atom. Some atoms are very light such as those of hydrogen. Since the weight of atoms increases as the number of protons increases, an atom of lead, as an example, has many more protons than an atom of sulphur, a lighter weight element. Hydrogen has only one proton, but uranium has ninety-two.

There are over 90 chemical elements most of which occur in nature. These are like oxygen, carbon, sulphur, chlorine, etc. All but twenty-some of these elements can occur in nature in several forms and still be that particular element. These related forms of an element which chemically react the same but differ in their mass are called *isotopes*.

Isotopes of chemical elements are important when one wishes to create a nuclear reaction.

The element deuterium is a heavy form of hydrogen,– an isotope of hydrogen.

In a nuclear explosion, the nuclei of the elements employed in the reaction interact, and in so doing, release a great amount of energy. The bond between the proton and neutron is many times greater than that between a nucleus and its electrons. It takes only a relatively small nuclear reaction to match the disaster of a large conventional chemical reaction-type explosion because of the greatness of the energy release.

Fission–[12] The heavy elements are employed in fission, such as isotopes of the elements uranium and plutonium. Uranium 235 and others are often mentioned in literature. Plutonium–239 atomic weight–does not occur in nature. Reaction occurs when a free neutron is directed into the nucleus of a fissionable atom, causing the nucleus to *"split"* in two, into smaller nuclei. By this reaction, one pound of uranium 235 or plutonium 239 could react to release the same energy as 8000 pounds of TNT.

Fundamentally, if Albert Einstein's famous well known equation holds true, material– whatever it might be– if converted completely into energy would result in an energy output of the weight of the material times the speed of light squared ($186{,}000^2$ miles/hr.). That is, a pound of material – coal, water, lead or whatever – if converted into energy would yield about 13.4 billion horsepower. For years this formula was for the blackboards of physics professors until Otto Hahn and Fritz Strassman discovered that uranium atoms could be split. This fission produced a tremendous release of energy, and the neutrons released by

81 Couch, Virgil L. "Survival Plans Your Company Can Use" Nation's Business, Reprint Department of Defense, Office of Civil Defense, December 1961

82 RCA– "Atomic Radiation" RCA Service Co.– Government Service Dept. 1958 Revised

83 Martin,Thomas L. & Latham, "Strategy for Survival" The Univ. of Arizona Press, Tuscon Arizona 1963

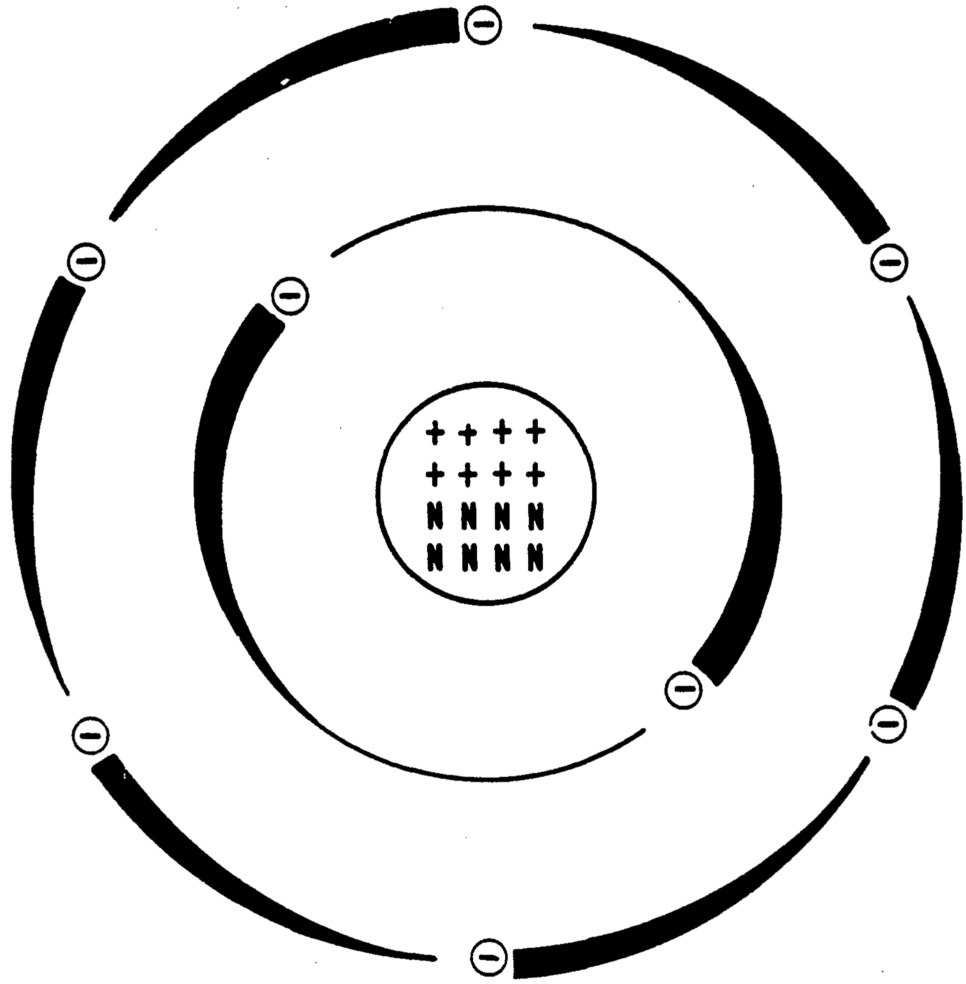


Figure 70. Determining Atomic Weight and Number

Oxygen has 8 protons, its atomic number is 8 it has an assigned atomic weight of 16. There must be 8 neutrons in the nucleus to bring Oxygen's atomic weight to 16. Eight electrons (-) balance the charge of the eight protons of the nucleus.

the split of the atom were capable of splitting others. This is commonly known as a chain-reaction. See Figure 71a.

Fusion—[12] In the case of fusion, instead of splitting the atom nucleus, a pair of light nuclei unite or *fuse* together to form a nucleus of a heavier atom. See Figure 71b.

When two deuterium (hydrogen) nuclei combine, helium-a heavier element than hydrogen— is formed and a great amount of energy is released.

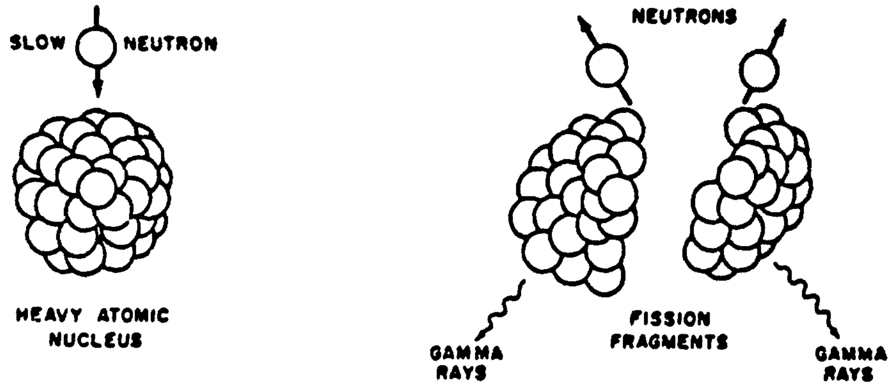
Glasstone[12] says that "fusion of all the nuclei present in one pound of hydrogen isotope deuterium would release roughly the same amount of energy as the explosion of 26,000 pounds of TNT." This is over three times the energy release of fission. It takes almost the heat of the sun to cause fusion. A fission reaction can trigger fusion.

This is the basis of a thermonuclear warhead or device. The term atomic weapon is now interchangeable with thermonuclear weapon, the latter terminology being preferred.

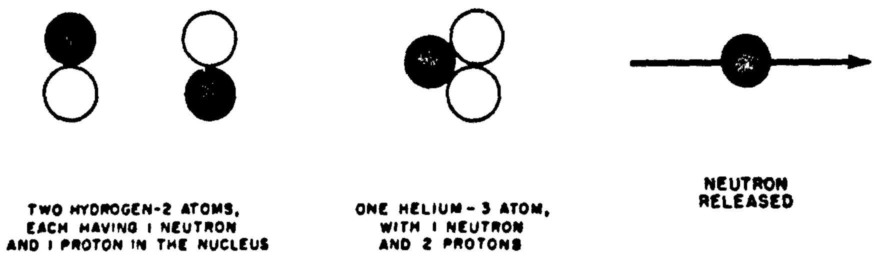
Neutrons with high energy are released during the fusion of certain hydrogen isotopes. If uranium and other fissionable material is still present when these neutrons are released, more fission can occur. A weapon that combines the reaction of fission and fusion can cause a release of an almost immeasurable amount of atomic energy.

The Forces of a Thermonuclear Weapon

The thermonuclear reaction creates a multiplicity of forces or features each of which in its own inimitable way



a. Fission process shown schematically



b. A nuclear fusion process

Figure 71.

A fission type explosion can generate temperatures upward to 100 million degrees. At these temperatures hydrogen atoms can fuse to create helium and release neutrons. These neutrons could cause fission if fissionable material is present. This is the reaction of a thermonuclear weapon. Electromagnetic waves of radiation, some destructive to blood cells and some capable of inducing destructive electrical forces, are generated in the reaction.

Source: Martin, Thomas L. & Latham, Donald C., "Strategy for Survial" The Univ of Arizona Press, Tuscon Arz. 1963

disrupts or damages various equipment and facilities of industry. Some of these are visible, as in the typical mushroom cloud, but much of the danger from such an explosion is invisible radiation. A partial list of effects is as follows:

The Blast (the shock wave from an air drop)
The Shock Wave* (The pressure wave from a burst)
The Shock (if a ground, near ground or water burst—a sudden impact)
Thermal Flash
Initial Radiation
Fallout Radiation
Electromagnetic Pulse
Ionization
Others

The temperatures reached in the reaction far exceed those of a hydrocarbon detonation. Thus, intense heat and light rays constitute a large portion of the energy released by a thermonuclear weapon.

In a fission type weapon, Glasstone suggests that the following approximate distribution of energy occurs:

Blast and Shock	50%
Thermal Radiation	35%
Residual Nuclear Radiation	10%
Initial Nuclear Radiation	5%

In a thermonuclear device, about half of the energy comes from fusion and half from fission.

*The term shock is being applied more to earth jarring seismic-like waves.

Detonations discussed earlier produce blast waves and thermal radiation. Since in these reactions the nucleus of the atom is not disturbed, there is no radioactive radiation as is the case in a nuclear explosion.

The Blast and Shock

As discussed in previous sections, the relative power of a weapon is related to a TNT equivalent. Thus, a device yielding the power of 1000 tons of TNT is called a one kiloton weapon. The bombs dropped on Japan and at Bikini were 20,000 tons rating or 20 kilotons yield. Only 2½ pounds of completely used material needs to react to give this release of energy. A weapon is never 100% efficient. A 20 megaton weapon is 1000 times greater. At 50 megaton or larger weapon is possible. The study of the thermonuclear reaction is a lifetime occupation. The reaction is portrayed much too simply here. But we in industry are more concerned as to what this device can do rather than how it does it. Let one summarize by saying that weight per weight of materials, a nuclear reaction's release of energy is greater by a factor of several million than what could be released in an explosion of combustible materials—a chemical reaction.

During a thermonuclear explosion, everything around the weapon is vaporized. Extremely hot gases result. The sudden expansion of these hot gases compresses the air around it instantaneously, which in turn expands enormously or is driven outward at explosive force, causing a compression or shock wave. These waves radiate outward from ground zero much like waves in water radiate from where the quiet waters of a lake were disturbed by a pebble. This shock front of compressed air moves at supersonic speeds causing destruction both because of the excessive pressure of the air and because of the accompanying wind velocity. The air particles are projected and blasted outward from the center of the reaction.

There are five generally recognized types of bursts: (1) air, (2) high altitude, (3) underwater, (4) underground, and (5) surface.

An air burst is one exploded below an altitude of 100,000 feet but high enough for the fireball, a blinding flash of sunlight brilliance, to miss the ground. A fireball of a megaton weapon is about 5800 feet across the brilliance. It reaches its full width in 2 seconds. On a clear day, this fireball will burn skin 12 miles away, and its heat can be felt 75 miles away. Unless the fireball is quite close to the ground, the nuclear radiation from such a burst will be minor. This would be a "clean bomb" in some parlance, since there is no dirt or debris to be contaminated radioactively. Low clouds absorb some of the heat; high clouds reflect it to the ground.

The fission products of the burst will spread out over a large area and be of minor importance on the ground as far as present knowledge is concerned.

A high altitude burst is defined as one above an altitude of 100,000 feet. This type burst, because of the thin air, creates more thermal radiation than the other types: as much as 50% of this fission energy becomes heat. The rare air reduces blast and shock to some extent.

In an underground burst or underwater burst, an earthquake-like shock wave is created. If near the surface, some air burst also results. The thermal radiation and initial nuclear radiation is absorbed within a short distance of the explosion. The residual nuclear radiations in these cases become very significant because of the large quantity of water or dirt becoming contaminated by particles of the reaction.

A surface burst is one occurring close enough to the surface to stir up great volumes of dirt, rock particles, and dust— thus creating air-borne radioactive materials. Radioactive fallout is created.

Glasstone, mentioned several times above, suggests that there is no sharp line of demarcation between the various type bursts, for each zone grades into those zones near it.

Some discussion of shock waves was given in the section on earthquakes.

Overpressure— The building up of air pressure by a thermonuclear burst creates a crushing effect on buildings, people and objects.

The compression of air from such a blast (increased pressure) is like a giant hand reaching out and crushing the buildings it grasps.

Overpressure is pressure above normal atmospheric pressure, whether it be caused by a refinery explosion or a nuclear weapon. The overpressure built up by the compressive wave is a static force and acts on a building by adding pressure to its walls— as would occur if the building were sunk into depths of water.

Overpressure is usually expressed in pounds per square inch (psi). Normal sea level pressure is 14.7 psi; a pressure of 17.7 would be a 3 pounds overpressure. The maximum pressure wave of a blast as it moves from ground zero is the *peak overpressure*. This pressure peak at the center of the blast is several hundred pounds, 200 to 400 plus depending upon the size of the bomb. Blast pressure from air bursts decreases outward from the point of the explosion, as do the shock waves from surface detonations.

Architects think in terms of square foot loading, so a one pound overpressure would add 144 pounds weight or push to each square foot of the building. One can see that 5 pounds overpressure would add 720 pounds to each square foot of the roof and walls of the building.

Table 40 shows possible refinery damage with respect to overpressure.

The overpressure of 5 psi is a critical value for most residential type construction, and office buildings completely fail before reaching such a load; actually, most buildings fail at 1 to 1.5 psi overpressure. Some are damaged at 0.5 psi. We have pointed out that control houses fail usually at 1 to 1.5 psi overpressure, and it was emphasized why they need to be built stronger. (See Warren's, et al. discussion on control house construction.)[1]

Wind Velocity and Pressure— Immediately following the peak overpressure is a wind of hurricane velocity. Like overpressure, wind velocity decreases outward from a blast. The pressure created on an exposed surface, due strictly to wind velocity, is considered here a dynamic pressure or wind loading. This value is proportional to the square of the wind velocity and to the density of air behind the blast front. Table

as and its discussion present this information. Buildings built to withstand high hurricane wind velocities survive better the effects of this force than do structures without this extra built-in strength.

Some structures can be blown in or over in spite of being able to withstand considerable static pressure. Cooling towers, fractionating columns, or other tall structures are quite sensitive to this "drag force". Often the bolts holding down the tower shear because of the leverage applied against them by the swaying tower.

The wind and peak overpressure act as a team to destroy all that are weak in their path. The overloading of the walls and roof of a structure because of the overpressure tends to crush or weaken the building. The wind that accompanies or follows along after the shock wave, blows down the shattered or weakened wall or structure. It is a "right and left to the jaw" sort of action, if one may borrow from boxing. See Figure 36 of Section I.

The shape of the structure, its length and height, its strength of construction, the presence of windows that can shatter and equalize pressure inside and out, the direction of blast movement and numerous other factors are considered in determining damage susceptibility of a structure.

The winds from a nuclear blast, taken velocity for velocity, are more damaging than winds of the same speed created by nature because of the length of their endurance. The wind from nature is puffy, and although even of high velocity, the turbulence of it allows a building to release its stresses as each gust relaxes. Not so in a blast! The winds are stout and continuous; dynamic pressures relax slower than peak overpressures. A building's elastic properties are over powered and not allowed to function in their usual manner. Table 29 of Section I shows the relationship between dynamic pressure and wind velocity. From the table, one expects a wind of 160 miles per hour to accompany a blast creating a 5 psi overpressure at a particular location. The wind loading itself accounts for a loading of 0.7 psi or 100.8 pounds per square foot in such a case.

Underpressure— A vacuum is left at the point of explosion. As the hot air that is projected outward from the fireball loses its momentum, it reverses and returns to fill in the void, thereby creating a negative or reverse wave that stumbles back over the debris left by the blast and shock waves. This is the suction or negative portion of the blast wave. What the shock and blast waves missed, the negative pressure finishes by creating a vacuum on the outside walls of the structure in the path of the destructive forces, quite like that done by a tornado. The action is somewhat like that of a tidal wave from the ocean advancing on to the shore only to return soon back to its point of origin.

One can expect this same air movement with any sizeable detonation. This negative pressure is considerably less than the peak overpressure at any comparative single point affected by an explosion.

Reflected Pressure— The initial blast from the explosion creates the *incident wave*. When this wave hits the ground or a solid object more dense than air, a *reflected wave* occurs, like waves of the sea bouncing off a pier. In the region near ground zero, the reflected overpressure will be more than twice the value of the peak overpressure of the incident wave, and strength varies with the angle at which the wave strikes.

The reflected wave is also called the *diffraction phase* of the blast. Since the reflected wave is moving in air already heated and rarified by the incident wave, it can travel faster. Eventually, under most conditions, it overtakes the original blast or incident wave, and the two fronts fuse into a violent wave. This distance is usually horizontally equal to about moderate burst height of the weapons. Greater burst heights increase the distance Mach effects occurs. This region where the waves have merged is called the "Mach" region. The two waves merge and an amplification of the blast pressure occurs. See Figure 72. (The interrelation of direct pressure and reflected pressure to form the Mach stem.)[84]

In Figure 72, at t_4 the incident and reflected waves have merged. This single front moves horizontally (the Mach stem), but as the reflected wave moves upward, the point of wave fusion (*the triple point*) moves upward. Above the triple point, two pressure waves are measured; below, in the Mach region, only one. Actually the triple point shown here in section or side view is in fact an expanding horizontal circle. Since the Mach stem is nearly vertical, the transient winds are parallel to the surface of the earth working with full fury on all vertical surfaces. Figure 73 is an artist's view of an impact pattern showing four zones of relative damage, the Mach stem and the two pressure waves above it.[26]

A surface blast creates ground shock waves like those discussed in Section I under earthquakes. This ground wave adds its influence to the destruction of buildings in its path. In large bombs, this is a substantial factor. See Figure 18 (Section I).

Thermal Flash— Upon detonation of a nuclear weapon, an intensely hot and luminous fireball develops like a small sun. Several tens of million degrees are reached at the most intense point. The flash of light, an ultraviolet radiation, can cause burns to the eyes if they are turned directly toward the blast many miles away in megaton weapons. The heat developed, an infra-red radiation, is almost beyond human comprehension. As mentioned, 30% and upward to 70% or so of the total energy of the weapon is expended in these rays. Only a few seconds elapse during this phase of the blast since these radiations travel at the speed of light (186,000+ miles per second).

Close in to the bomb drop, the heat is intense enough to melt rock, steel, glass, the paint on buildings, to buckle steel beams, burn wooden buildings,— but as the heat attenuates away from the blast, the amount of fire protection necessary rapidly diminishes.

Figure 74 and 74a shows a comparison of the thermal radiation from 1, 10, and 100 megaton weapons.

Electromagnetic Pulse— A nuclear explosion yields electrical impulses not too unlike those static discharges that create lightning generated in a huge thunder-cloud. The potential damage to sensitive low voltage electrical equipment is quite serious.

---

84 Advanced Research, Inc.— Prof. Guide on Reducing Vulnerability of Industrial Plants to the Effects of Nuclear Weapons— OCD 1964— PSD–PG–8.

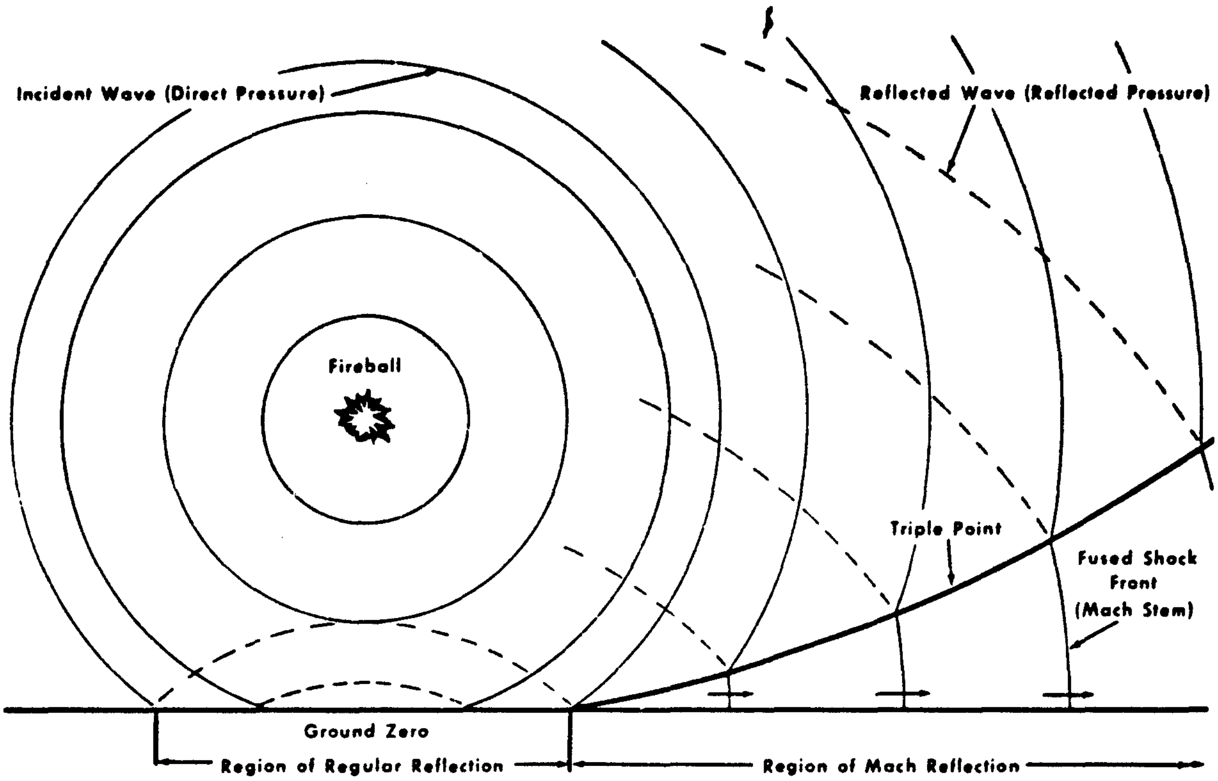


Figure 72. Interrelation of Direct Pressure and Reflected Pressure to Form the Mach Stem [84]

"The EMP[85] is electromagnetic in form and the bulk of its energy lies within the 'radio frequency spectrum' (ranging from power-line frequencies to radar system frequencies). Hence, another term for EMP is 'radio-flash'. EMP should, therefore, not be confused with other weapon burst outputs, such as neutrons, which might also damage electronic equipment. To emphasize this differentiation, the term 'electromagnetic' will be associated with the EMP (or radio-flash) phenomena and effects.

A full discussion of these electrical currents is not warranted here except to say that the effect is very widespread and can be disastrous to solid state and other electronic equipment and to radio communication. The low and medium radio frequency bands from 30 to 3000 kilo Hertz are not seriously affected, but high frequency, 3 to 30 mega Hertz transmission, can under some circumstances seriously be impaired or interrupted for several hours after the blast. The electromagnetic wave cuts invisibly through wires and can induce large voltage surges in electrical equipment. Long cables, piping, conduit, antennas, guy wires, overhead power lines, steel supports, metal roofs, automobiles and trucks, buried pipes, metallic fencing, railroad tracks, aluminum airplane skin and almost anything metal can "collect" these electrical charges. Communication lines and some radio frequencies can be blocked out during an electric impulse "shower". For example, following the August 12, 1958, high altitude burst set off by the United States over Johnson Island, there was a two-hour communication blackout at certain radio frequencies."[63]

Under some circumstances, voltages as high as 3000 volts or so can be induced into electronic circuits designed for

85 Bridges, J.E. and Weyer, J.– "EMP Threat and Countermeasures for Civil Defense" Illinois Institute of Technology– Contract DAHC20-68-C-0198 November 1968– For Civil Defense

Figure 73. Initial Impact Pattern

Source: Civil Defense Preparedness in the Electric Power Industry

low voltage operation. One does not need to imagine what problems could be created in a computerized operation.

The table below lists equipment easily susceptible to damage.[85] These are listed in the order of decreasing sensitivity to damage effects.

Microwave semiconductor diodes
Field-effect transistors
Radio-frequency transistors
Audio transistors
Silicon controlled rectifiers
Power rectifier semiconductor diodes
Vacuum tubes

Thus, systems employing vacuum tubes are far less susceptible to EMP effects than those employing transistors.

Various electronic or electrical systems are subject to malfunction.

Most susceptible

Low power, high speed digital computer (upset) either transistorized or vacuum tube

Systems employing transistors or semiconductor rectifiers (either silicon or selenium), such as:

Computers
Computer power supplies
Transistorized power supplies
Semiconductor components terminating long cable runs, especially between sites
Alarm systems
Intercom systems
Life-support system controls
Some telephone equipment which is partially transistorized
Transistor receivers
Transistorized transmitters
Transistorized 60 to 400 cps converters
Transistorized process control systems
Power system controls, communication links

Refinery control houses containing computerized equipment will need special shielding and line protectors to prevent burning of the equipment because of high voltage surge.

Less susceptible:

All vacuum tube equipment (does not include equipment with semiconductor or selenium rectifiers)

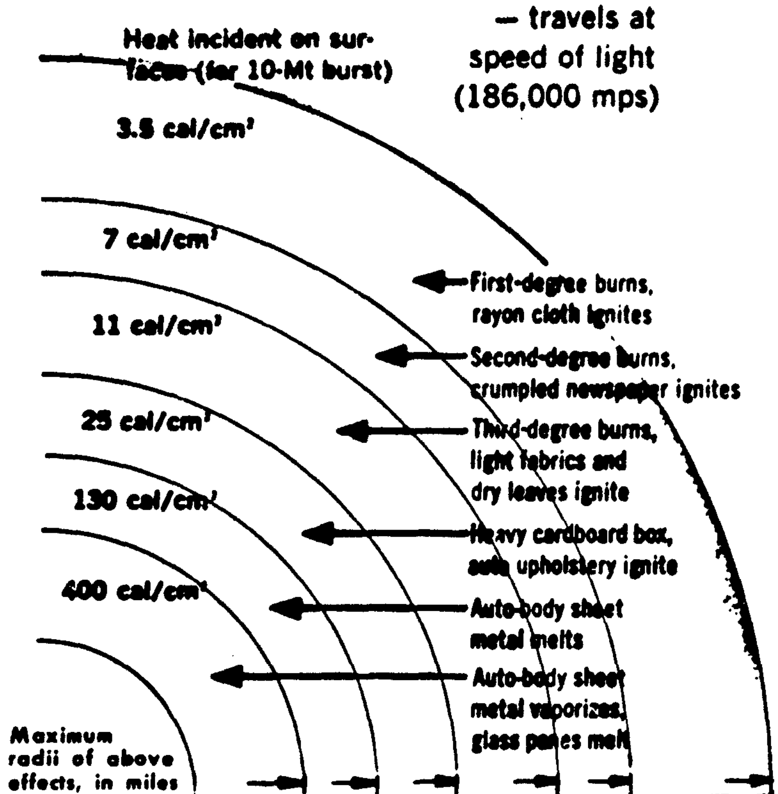
Transmitters
Receivers
Alarm systems
Intercoms
Teletype-telephone
Power-supplies

Equipment employing low current switches, relays, meters

Alarms
Life support systems
Power system control panels
Panel indicators, status boards
Process control

Hazardous equipment containing

Detonators
Squibs
Pyrotechnical devices
Explosive mixtures
Rocket fuels



1 Mt	Air	[illegible]	[illegible]	5.5	8	9	13
	Surface	0.9	1.6	3.3	5	5.5	8
10 Mt	Air	4	7	15	22	25	35
	Surface	2.4	4	9	13	15	21
100 Mt	Air	11	19	45	60	70	100
	Surface	6.5	11.5	27	36	42	60

About 35% of total bomb energy goes out in a burst of heat, uniformly radiated. Heat level falls rapidly with distance, as shown in calories per square centimeter at successive circles, above. Figures below give clear-day radii of circles for three weapon sizes, two types of burst. Also shown are possible effects on materials, people

Figure 74. Thermal Radiation

Other
- Long power cable runs employing dielectric insulation
- Equipment associated with high energy storage
- Capacitors or inductors

Least susceptible:

High voltage 60 cps equipment
- Transformers, motors
- Lamps, filament
- Heaters
- Rotary converters
- Heavy duty relays, circuit breakers
- Air insulated power cable runs

The less susceptible equipment or components can be made more susceptible if they are connected to long exposed cable runs, such as intersite wiring or overhead exposed power or telephone cables.

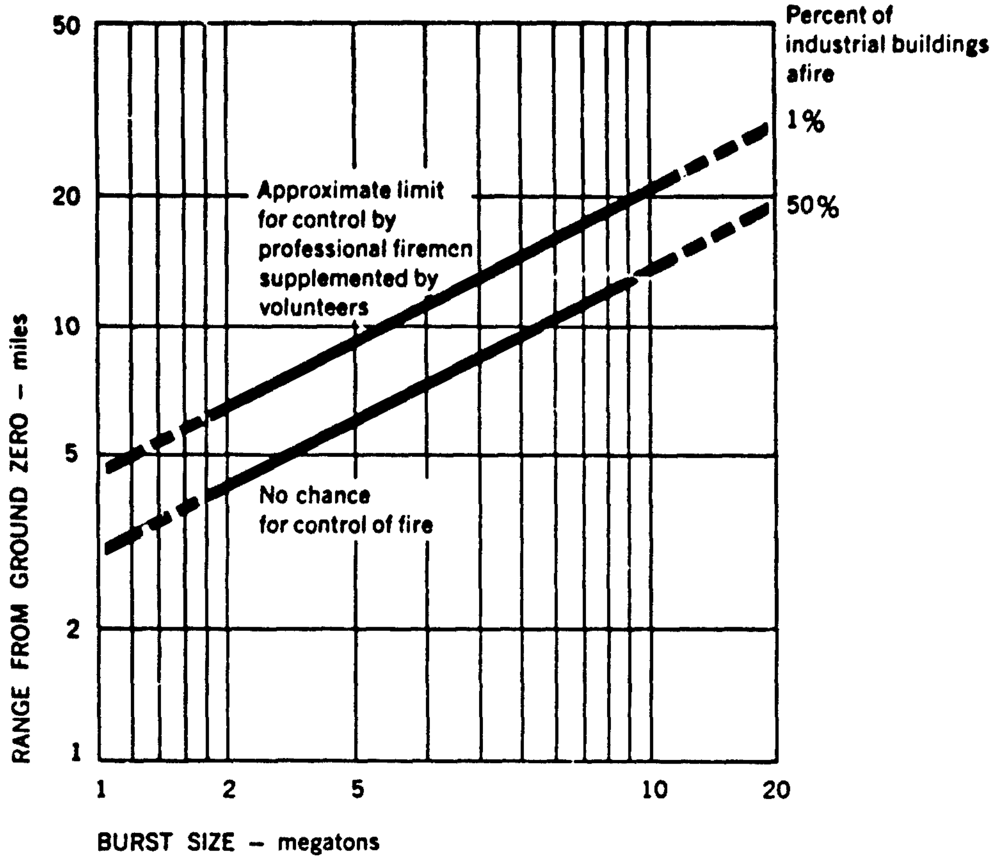


Figure 74a

Fallout

As the materials within a bomb react, a number of electromagnetic rays are created. The rays most damaging to humans are the *gamma rays*. These are like X-rays, but much stronger, and when one is subjected to a strong overdose of these rays, serious illness or death can ensue. The amount of gamma ray created depends on the size of the bomb. For smaller or kiloton weapons, the "kill radius" for the gamma rays exceeds that caused by the blast pressures. Protection of people near "ground zero", therefore, must be against blast pressures and *initial gamma radiation* or *prompt radiation.*

There are two general types of gamma rays in the initial radiation: one, those due to fission, and two, those due to nitrogen capture. The prompt radiations are approximately related in a real extent to the destructive levels of the blast. They are dangerous in the destructive blast area. These rays are not serious consideration in areas some distance away from the blast and areas affected only by radioactive fallout.

Those rays due to nitrogen capture, strike out a greater distance than those due strictly to fission.

In the initial radiation, there are two other important types of radiation,— neutron radiation due to fission, and neutron radiation due to fusion. While these radiations are intense, still the dose decreases very greatly as the distance from the burst increases. Close to the bomb burst, the dose level is in astronomical figures, but one could say— so what! A structure of military strength will be massively shielded against all of these radiations, but industrial installations near ground zero will be disintegrated. It is not economically feasible to build refineries to withstand a direct hit.

Our concern is great for the people working in installations beyond the damaging blast effects of the bomb but showered by minute windblown dust, each particle carrying damaging radioactive materials— fallout.

The frontispiece of Section II shows the mushroom cloud typically associated with a nuclear explosion. This is a photograph of a surface blast. Much dirt and debris are sucked up into the stem and cloud of the fireball. There, because of the intense heat, much of the material vaporizes. The dust and debris intermix, then are churned in with vaporized radioactive products of the bomb, like tumbling clothes in a washing machine. This intimate contact of dirt

and fission product impregnates each fragment as it cools and solidifies whether it be a micron in diameter (0.00004 inch) or several millimeters across.

All radiation emitted later than one minute after an explosion is called the *residual radiation,* and air-borne fragments rain and settle down on the earth for miles around. This is called "fallout".

Within the fireball, 200 different isotopes of 35 elements or so take part in the radioactivity. It is calculated that about 2 ounces of fission product are formed for each kiloton of fission weapon yield. "The gamma ray activity of 2 ounces of fission product one minute after the explosion is roughly equivalent to that of 30,000 tons of radium."[87]

The distance travelled by a particle depends on its size and the wind velocity at the time of the event. Early fallout is considered to be that material falling to the earth within 24 hours of the blast. *Delayed fallout* is later dust precipitation.

Since the head of a nuclear cloud might reach an altitude of 30 miles and radioactive material is projected from the cloud, there can be a delay of as much as 30 minutes or more before radioactive material hits the earth even close to the target area. As distance increases from the blast area, the time of fallout increases.

The early fallout material is fresh from the mushroom cloud; it is strongly radioactive. It is this material that is of greatest importance in fallout design. People must be protected from its killing radiations. Once on the ground or roofs of buildings, the radioactive dust and sand continue to give off their deadly rays. It could take 2 weeks or more time in some conditions to have safe working conditions after such a "shower".

Figure 76 shows an artist's concept of this dusting by fallout. Wind will blow fragments and thus spread out the affected area downwind.

Roetgen— The unit of measure of the quantity of gamma ray radiation is the roentgen or rad. This unit of measure is used like a pound, an inch, a gallon, a watt, or other units of measure. By practice and use of a unit, we understand its relative value. A roentgen is the quantity of gamma radiation which will give rise to the formation of $2.^{08} \times 10.^{9}$ ion pairs per cubic centimeter of dry air at standard temperature and pressure (60° F. and $14.^{9}$ psia). A better understanding of the term is in its relation to damage to biological tissue and its effect on human beings. Thus, a roentgen is used to measure related human reaction to radioactive ray exposure. *Dose rate* is the number of roentgens per hour to which one might be exposed.

Radioactivity reduces rapidly but varies for various isotopes. *Half-life* is the time required to reduce radioactivity by half its initial value.

For practical purposes, the Seven-Ten rule can be applied. *For every seven-fold increase in time after the explosion, there is a ten-fold decrease in dose rate.* For example, starting at a level of 1000 roentgens per hour dose rate, after 7 hours the dose rate would have reduced 10 times or to 100 roentgens per hour; about 2 days after the explosion, the dose rate would be only 10 roentgens per hour. Actually, decline is faster than this.

Radioactive exposure is accumulative. Exposure to rays at one time must be added to exposure at a later time. The body can tolerate some exposure, but various body functions fail with increased dose rates. Lymphoid tissue and bone marrow, testes and ovaries, skin and hair, blood vessels, smooth muscle and nerve cells are sensitive to radiation in this order. Persons undergoing radioactive therapy could already be at the peak of their tolerance at blast time.

The age and health of a person also contributes to ones ability to withstand radioactive exposure. Children and old people are greatly affected.

Studies of Japanese casualties and later experiments with laboratory animals have guided medical personnel in their evaluation of a human's ability to withstand radioactivity.

The United Nations— Atomic Bomb Casualty Commission reports that studies made of pregnant Japanese women exposed to 200 rad had 36% mentally retarded children. Between 100 to 200 rads, the incidence dropped to 9.3%. Between 50 to 90 rads, it dropped to 4.55%. An X-ray photograph exposes a person to 1 rad or less. An unexposed control group had less than 1% mentally retarded children.

Adults in good health and of active age can withstand upward to 100 roentgens without much immediate results. Some nausea could be experienced. From 100 to 200 roentgens upward to 50% of those exposed will show nausea in 3 hours. White blood cells decrease, some medical treatment could be necessary. Death would be improbable.

With from 200 to 600 roentgens, almost everyone would become violently sick with vomiting at a dose of 300 roentgens. Severe leukopenia, a loss of white cells, is noticeable. Purpora, purple spots and extra vasation of blood through the skin, is noticeable. Epilation, loss of hair, results at an exposure of 300 roentgens. Blood transfusions and antibiotics are necessary. Up to one year is required for recovery. Some die at an exposure of 250 roentgens from hemmorrhage or infection in two months.

Severe radiation sickness is experienced by those exposed to 600 to 1000 roentgens. Bone marrow transplants, transfusions, antibiotics and great care would be all that could save one so exposed.

A dose of 1000 roentgens is almost certain death. Diarrhea, fever, a circulatory collapse, convulsions, tremors, lethargy and loss of muscular control result from such exposure.

The area covered by both the early fall-out and the delayed can be great depending on the wind, atmospheric conditions (localized rains) and amount of dirt and debris sucked into the thermonuclear explosion. The softness of the soil and size of the bomb and its explosion height determine also the amount of dust created by the blast. Both early and delayed fallout is important, but most effective shelters are designed to protect against material falling to the earth in the first 24 hours after the detonation (early fall-out).

Fortunately, because the rate of decay, as mentioned, follows a straight line log-log decline, the longer the radioactive particle travels in the air before settling, the weaker and less dangerous it becomes. Table 41.

87 Official of Civil Defense— Shelter Design and Analysis— Vol. I TR-20 June 1968.

A 20mt NUCLEAR EXPLOSION (Surface Burst) 88

In contrast to air bursts where fallout goes mainly to the stratosphere and may travel far, surface bursts are characterized by heavy local fallout. This results from great amount of debris swept up into the fireball. Like the materials of the bomb, such debris is initially vaporized. Material swept up later may be only melted. When the vaporized materials, including fission products and materials made radioactive by neutron bombardment, condense into fin- particles, many of these ... to larger debris particles. Resulting size keeps particles from rising high, causes them to settle out over large areas as the radioactive cloud moves with the wind. 86

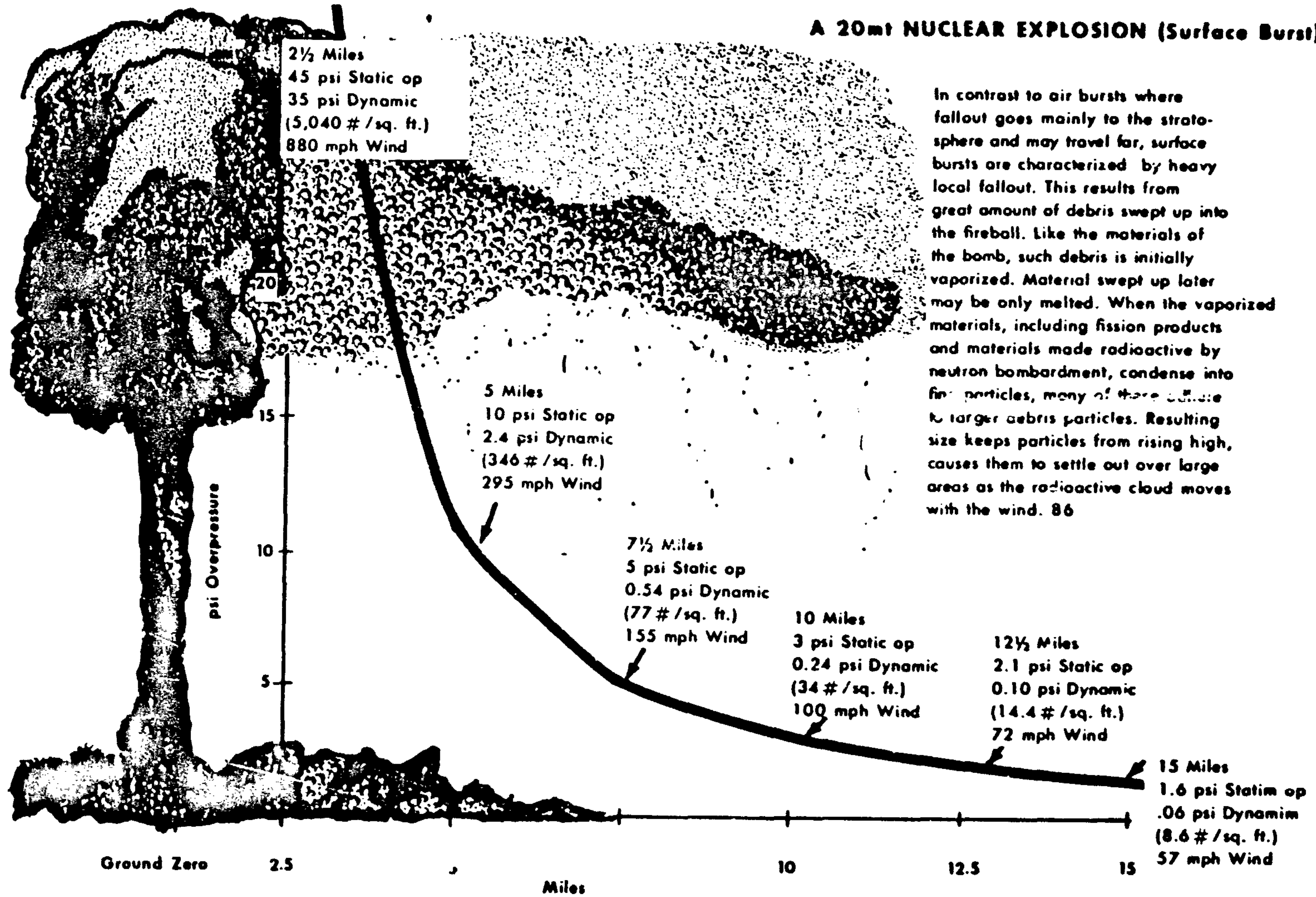


Figure 76.

See: 88 OCD Civil Defense Aspects of Waterworks Operations - Dep't of Defense FG-F3-6 June 1966.
86 Editors McGraw-Hill Publishing Co.

It is practice to rate fall-out to the reading near ground zero one hour after the explosion (H + 1 hr.). This is the *one-hour reference point* and is used in dose rate or exposure calculations. The decline in radiation from charged particles is as follows:

Table 41. Radioactivity Decay Rates

Relative Dose Rates on a Percentage Basis[12]

Time After Explosion	Relative Dose
1 hour	1.000
2 hours	.440
3 hours	.230
5 hours	.130
6 hours	.100
10 hours	.063
24 hours	.023
1 week	.00215
2 weeks	.0013
4 weeks	.00031
6 weeks	.00024

Example:

Time After Explosion	Dose Rate in Roentgens/hr.
1 hour	3000
5 hours	390
10 hours	189
24 hours	69
1 week	6.45
4 weeks	0.93
6 weeks	0.72

Decay rate is usually taken to be proportional to (time$^{1.23}$). Glasstone, The Effects of Nuclear Weapons,[12] discusses this calculation in detail.

If the burst occurred during a wind of 15 miles per hour, a point 75 miles away from the blast site would be reached in 5 hours. The airborne radioactive particles would be considerably weaker than those reaching the ground closer to the explosion. But, after the dust cloud has reached a location, a deposit will accumulate on buildings at a rate faster than the radioactive rate of decay, so intensity increases at first, then as the cloud passes on, the activity decreases at the rate shown in the tables.

It is usual to measure dose rate by a Geiger counter or measuring device held 3 feet off the ground or floor of a building in which you are seeking shelter. A dosimeter is a device that records one's accumulative exposure to damaging rays. See Figure 77. Everyone should spend some of his time studying course work on the effects of radioactive fallout, how it is measured and how one can protect his own life and the lives of his family. Civil Defense offices on local, state and federal levels have many pieces of literature on these various subjects.

There are several fundamental points important to a refinery manager.

1. Radioactive fallout from an all out nuclear attack will endanger all of the lives of the country, but because of wind currents and local weather conditions, will subject only 75% of the country to dangerous fallout.
2. The farther away a plant is from a blast, the more time it has to put emergency shutdown procedures into action.
3. A plant may be miles away from an explosion but can be put out of action because of radioactive fallout.
4. Unless shelters are provided in a refinery at places where workmen can control the operation, either the plant must be shut down at the first warning of enemy attack or it will have to be abandoned to run itself or blow up shortly after the attack.
5. As radioactivity decreases, short exposures to fallout are not harmful, but since the body damage is accumulative, no more than 200 roentgens exposure should be acquired totally by a healthy person. Some cannot take this amount.
6. Canned or covered food can be exposed to fallout particles. It does not become radioactive because of its exposure to gamma rays. Washing away the radioactive dust removes the harmful materials. One cannot take much active fallout material internally without harm.
7. A number of employees need to be trained in each installation, not only in radiological monitoring, but also in shelter design.
8. Civil Defense training pays big dividends in time of the occurrence of natural disasters. The protection from radioactive fallout will be discussed in that section later.

A nuclear weapon dropped on a target will be a ground burst if maximum fallout is to be generated and an air burst if maximum blast damage is desired. A drop could be accidental. The most destructive altitude for a detonation 1 megaton weapon is about 6,500 feet. See Figure 78.[89]

Heat, initial nuclear radiation, blast pressure, wind and radioactive fallout are created by the explosion. See Figure 79.[89]

---

89 Staff College Office of Civil Defense "Civil Defense, USA" Unit 2 Department of Defense Office of Civil Defense SM5.2 June 1968

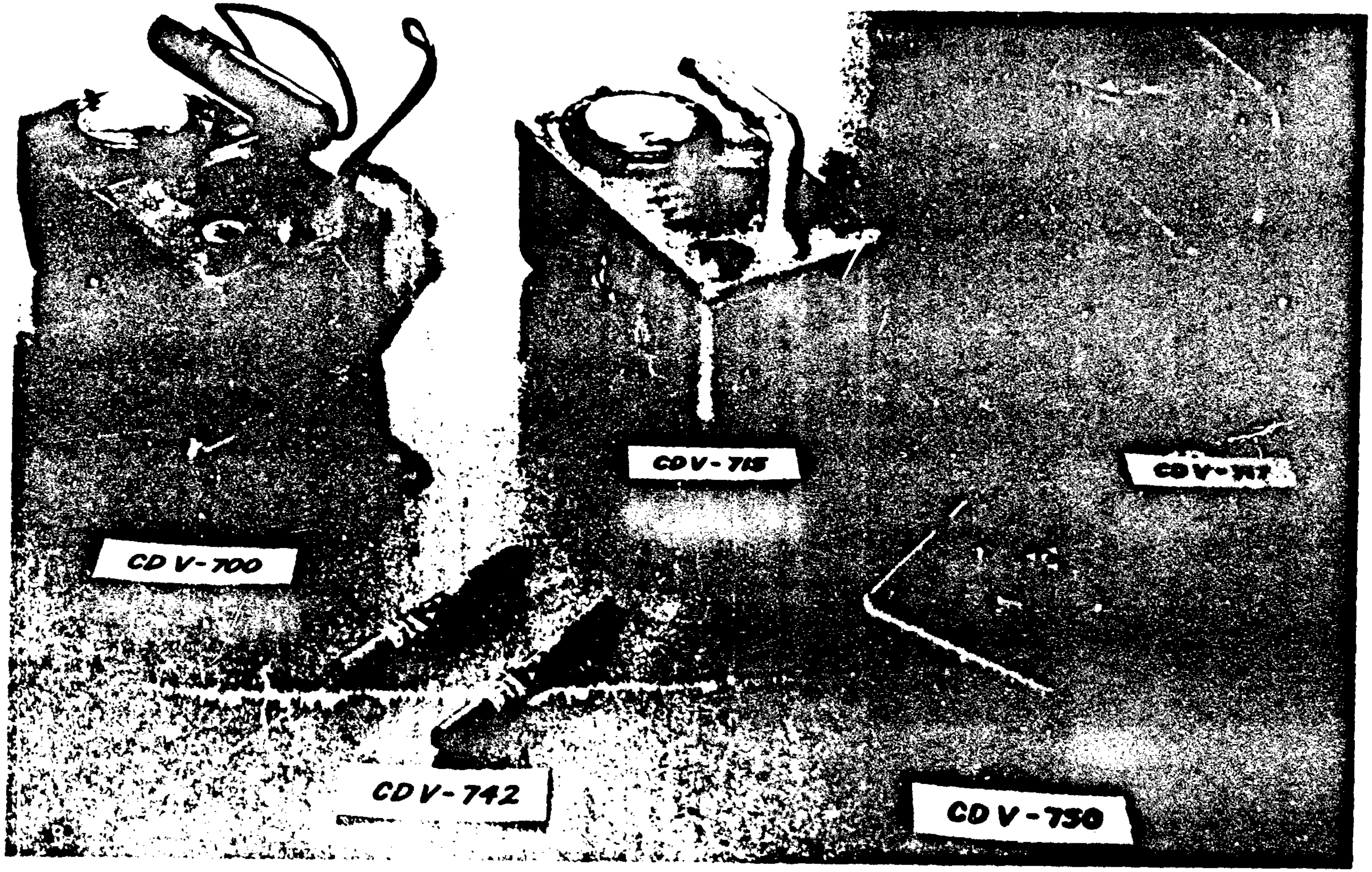


Figure 77. CDV-715 – 0-500 B/hr. meter CDV-700 – 0-50 mR/hr. meter CDV-742 – Dosimeter- to detect accumulative exposure CDV-717 – 0-500 R/hr. meter within 25 feet of cable on detector CDV-750 – Recharge for dosimeter.

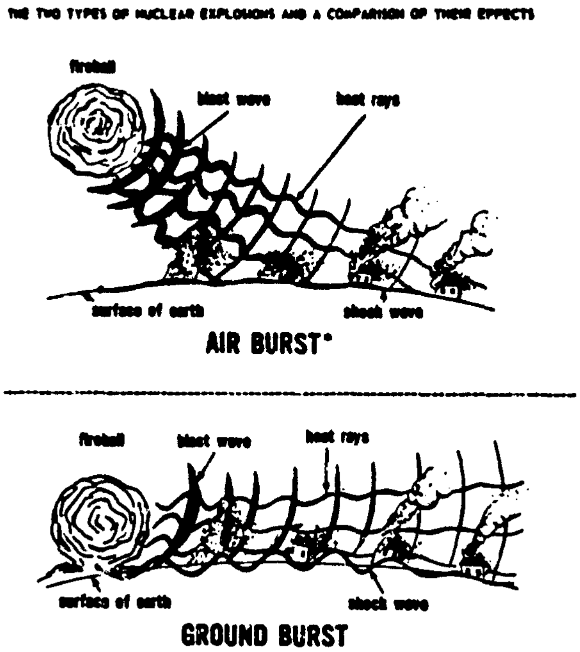


Figure 78. The Two Types of Nuclear Explosions and a Comparison of Their Effects

*The effects of an air burst depend upon the power and altitude of the burst. The most destructive height for a 20 KT weapon is about 2,000 feet; for a 1 MT weapon, it would be about 6,500 feet, etc.

(Source: Civil Defense, USA)

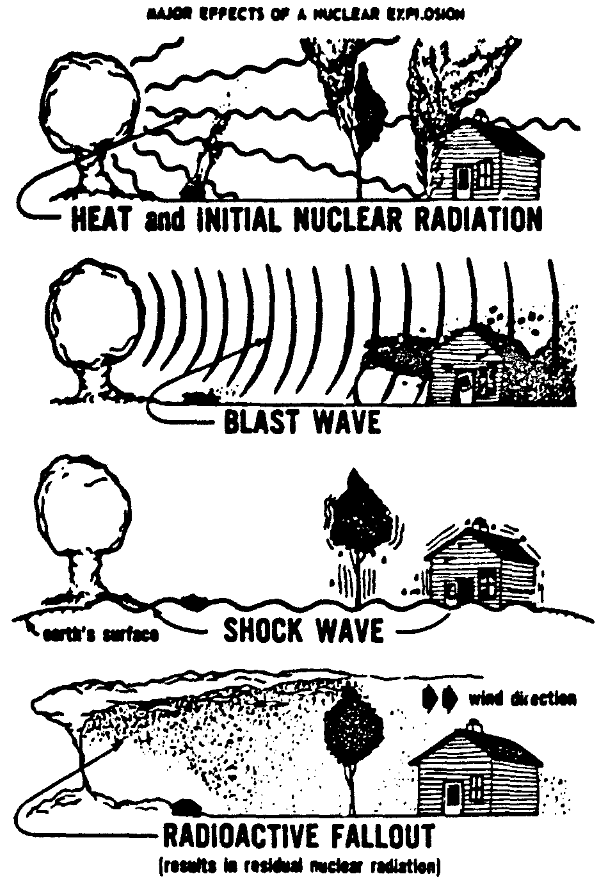


Figure 79. Major Effects of a Nuclear Explosion

(Source: Civil Defense, USA)

Chapter IX

DAMAGE EXPECTED FROM NUCLEAR BLAST

Blast Damage

A nuclear detonation causes destruction of several types such as blast damage (both overpressure and wind force), heat damage, electrical damage, and fallout. These items of destruction can be further considered in two lights, damage causing structural failure and damage to life.

Blast effects on structure and electronic pulse damage to sensitive equipment, and to some extent the thermal radiations, work more on things, whereas radioactive fallout destroys life. It is evident that people are injured by collapsing buildings and by heat when caught unprotected in the blast, but, given some warning, most people will find protection, except in the area of ground zero.

Figure 80 illustrates a generalized concept of the blast and (Figure 80) fire damage caused by a 20 megaton bomb. Note the total destruction by blast up to 5 miles from the center of the fireball.

Various authors of literature on blast damage have used different overpressure limits or ranges in determining whether the damage from a blast is severe, moderate or light. Some early literature designated four categories as A, B, C and D damage zones, the D zone being that zone with light damage.

Zone	Degree of Damage
A	Total Damage-Maximum psi over pressure to 12 psi
B	Heavy or Severe Damage—12 psi overpressure to 5 psi
C	Moderate Damage—5 psi overpressure to 2.5 psi
D	Light Damage—2.5 psi overpressure to 0.5 psi

It is improper to be so finite in equating damage entirely to overpressure, for, as mentioned, the construction of the building or plant, its age, its exposure, the altitude of the blast, and many other variables cause variations in the pressures developed and the response to them. Each zone blends into the next, so there are no sharp boundaries. Values given here are approximate and should be used as a general guide for probable damabe assessment. Let us review the fact that as blast altitude increases to an optimum height, the value of the overpressure increases outward from ground zero. This relationship is shown in Figure 81.

Figure 82 is of general interest to those evaluating blast damage from a theoretical bomb drop. Here again, the zones of damage under actual conditions would not be sharp lines of demarcation. For blast damage evaluation, lines of average conditions must be used, and there are indicated on the graph. The graph is based on the fact that the blast damage varies with the cube root of the energy released from the bomb.

The vertical lines show bomb size; the lower line, the Hiroshima bomb times various factors, i.e. 20,000 X various multiples of sizes. The top scale is in equivalent megatons. Along the side, scaled distances are in miles. To find the relative condition of an area 3 miles away from a fireball of a 1 MT blast, start at 3 on the left hand scale and trace horizontally to the 1 MT line. The area in question would be in the B zone or severely damaged. Figure 82a is similarly used.

One can use the graph in another way. To find the distance a moderately damaged area (C) would be from the ground zero of a 1 MT explosion, start at the top of the graph at 1 MT, look downward until the edge of the C zone is reached and read the distance either to the left or right to find the mileage. Similar distances can be found for bomb sizes up to 40 megatons.

To cause the greatest damage, there is an optimum burst height for every size bomb. Further, as a bomb size increases, its effectiveness increases, but not in proportion to its size. The larger the bomb, the less efficient it is per unit of energy. A large bomb does more damage than a small one, but a 10 MT bomb *does not do* 10X the damage of a 1 MT bomb. Ten 1 MT bombs properly spaced on target will do considerable more efficient work than one 10 MT bomb dropped in the same area. It is probably because of cost and delivery problems that the 50 or more megaton bombs will not be commonly used. One might expect many 1 megaton bombs and others up to 20 megatons in size. Whether a structure is sensitive to overpressure or wind velocity or both adds to the problem, making the suggested damage zones average conditions. The *Total Descrution Zone* is not much in question. In this area, most people will be killed. A few in heavily protected areas could survive. In the *Heavy Damage Zone,* it is assumed that structures and buildings cannot be repaired after the blast. They will need to be torn down and be rebuilt. In the *Moderate Damage Zone,* conditions are such that major repairs are required to restore the building or equipment to use. A *Slightly or Lightly Damaged Zone* structure might have broken windows and crashed walls, but it would be useable with only minor repairs. In wartime, chemical industry subjected to less than 5 psi overpressure is about all that can be considered worth rebuilding. It has been discussed in Section I that control houses and cooling towers become generally useless after exposure to 1 to 1-1/2 psi overpressure. If these items are shut down, the plant is down until emergency repairs can be made. Fires caused by ruptured oil lines add to the confusion and damage.

Tables 42, 43, 44 and 45 list some rather common items damaged at exposure to various overpressures. Tables 44 and 45, from Glasstone, compare damage from the diffraction phase and drag phase.

Figure 83, partly based on material shown in Table 39 in Section I, gives probable failure of refinery equipment when subjected to excessive overpressures.[91]

---

91 Walker, F. E.—Estimating Production and Repair Effort in Blast-Damaged Petroleum Refineries—Stanford Research Institute-July 1969.

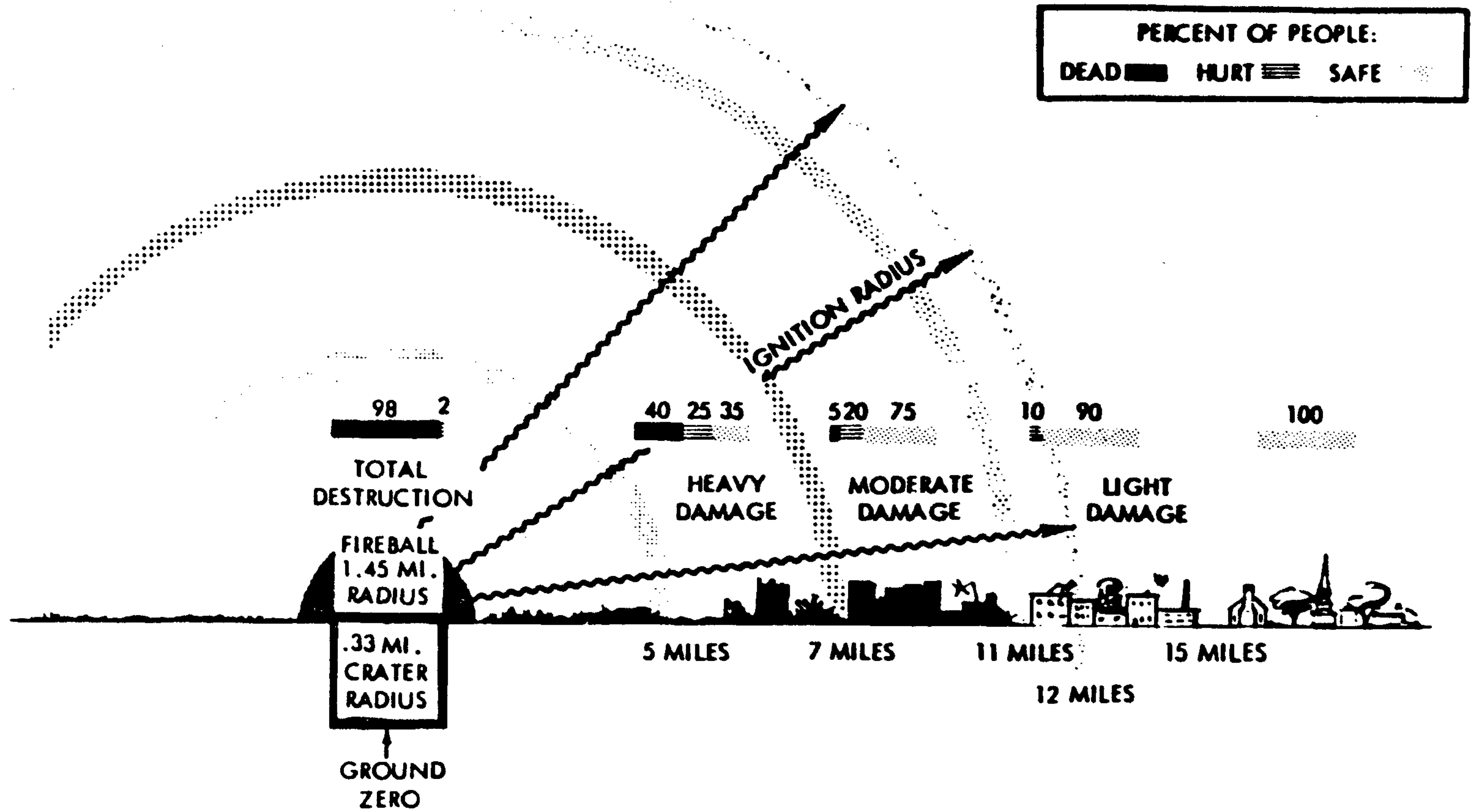


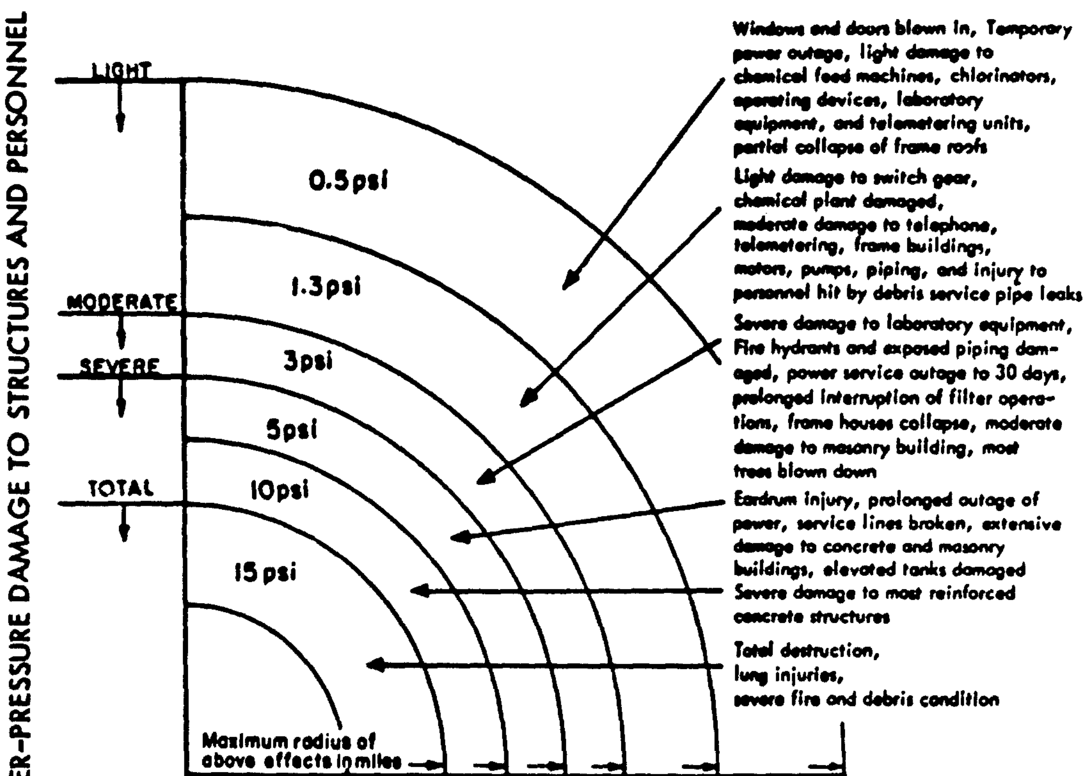
Figure 80. Effects* of a 20 MT Blast - Surface burst

If burst is elevated to altitude maximizing reach of blast damage:

"Moderate Damage" from blast is extended from 11 to 17 miles

"Ignition Radius" (ignites newspaper) is extended from 12 to 17 miles

* The results given are based only on blast and heat effects. The effects of shock and fallout are not taken into account.



1Mt	Air	2.1	2.7	4.3	6.1	11.0	20.0
	Surface	1.6	1.9	2.7	3.7	6.1	12.0
5Mt	Air	3.6	4.6	7.4	10.4	19.0	38.0
	Surface	2.7	3.2	4.7	6.2	10.6	20.8
10Mt	Air	4.6	5.9	9.3	13.2	24.0	50.0
	Surface	3.4	4.2	6.0	8.0	13.3	26.2
20Mt	Air	5.8	7.4	11.8	16.8	30.2	64.0
	Surface	4.2	5.2	7.5	10.0	17.0	33.0

Figure 81. Ranges from Ground Zero for Various Overpressure and Blast[90] Damage Effects as Function of the Energy Yield

Much of this discussion as to refinery damage from a severe blast relates directly to everyday problems within the plant. The care used to prevent detonations and explosions was discussed in Section I. One should not forget that the problem of damage assessment or what is to be expected during an attack is to be complicated by secondary effects created by broken lines, caved-in control houses and switch gear houses, and collapsed tower supports to say nothing of the exposure of the men to radioactive fallout a short time after the blast. One needs to add and compound the hazards faced daily to those created by a nuclear attack to see the probable situation.

We are living in a new era. Weapons of the past are like bows and arrows compared to cannons. In World War II, in one of the greatest air raids on England, 437 aircraft attacked Coventry. A count of 394 tons of high-explosive bombs, 56 tons of incendiary bombs, and 127 parachute bombs were dropped. The death toll was 380 killed and 800 injured. There was extensive building damage.

Compare this with a small atomic bomb, the one dropped on Hiroshima, a 20,000 T weapon. Three aircraft flew the mission; only one bomb was dropped. At least 70,000 persons were killed, 70,000 or more were injured, many more suffered some later disorders, 62,000 buildings were destroyed, and 4.7 miles of the city were left in rubble. It is hard to imagine operating conditions under nuclear warfare, for so little actual experience exists. The records for two bomb drops- plus information for many tests- indicate that

90 Department of Commerce "Facility Protections for Food Processing Plants," FG-F-3.54USGPO 0-404-276, 1970

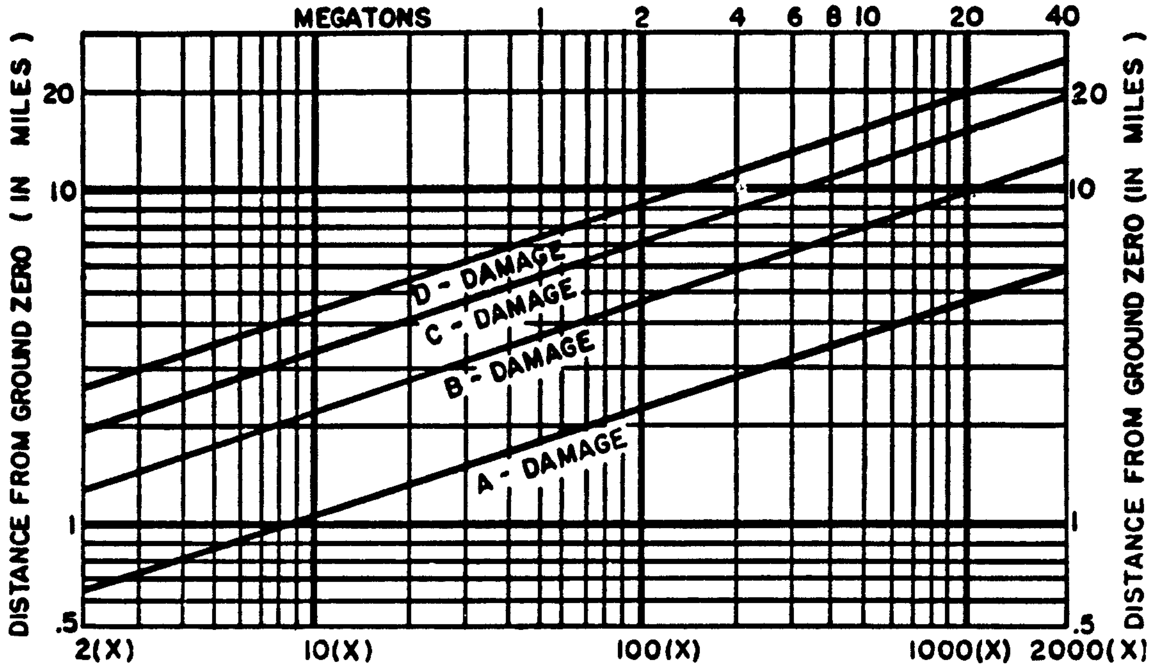


Figure 82. Bomb Size in Terms of Hiroshima Bomb and in Megatons (Hiroshima Bomb = 1 (X) = 20,000 Tons TNT, One Megaton = One Million Tons TNT)[90] Blast Damage Radii for Nuclear Weapons.

if industry is to exist in a modern warfare situation, there is much effort needed to prepare for such conditions.

Protection from Blast-Great emphasis is being placed on fallout protection since this is the greatest threat to large masses of people. Blast protection is a special problem, but refineries have interest if for no other reason than to have protection from their own potential explosions.

Much has already been included on the construction of blast resistant control houses. Many companies now find it wise to incorporate this added protection in their new plants. Control houses are being built to withstand at least 3 psi overpressure.

Not much can be done to existing buildings to increase their strength. Much information is available for architectural engineers from Civil Defense sources.

Many companies have gone underground. This is an answer to a number of problems. The use of salt mines or other mines in solid rock is becoming quite popular. Standard of New Jersey and others have emergency offices at Iron Mountain, near Catskill, New York. The John Hancock Berkeley Building in Boston, Massachusetts, is a steel and concrete building faced with granite and sandstone capable of withstanding 15 psi overpressure. This building can safely keep 6000 occupants for 10 days and withstand considerable blast pressure. The Industrial National Bank of Providence, Rhode Island, was discussed in detail in Section I.[79]

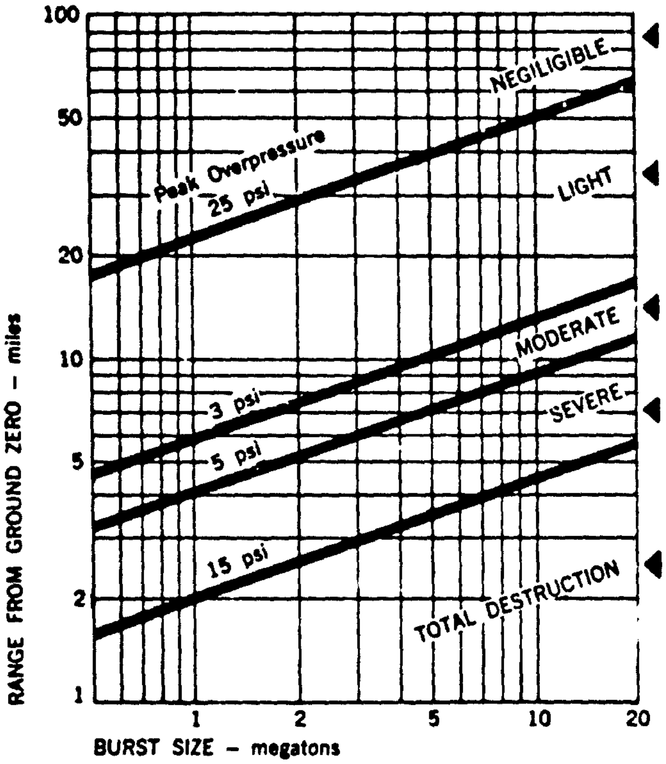
Earthquake-resistant buildings must have some extra strength built in to withstand shock. Generally the blast resistance of a structure can be increased by adding sturdy connections between beams and columns. Extra bracing and the use of reinforced concrete which also contain the frame will give a structure maximum blast resistance.

"Essential features of blast-resistant shelters are structural[88] strength to resist blast loads to the selected overpressure level, an access door of corresponding strength, a protected ventilation system to permit occupancy of the shelter until fires have subsided, and adequate nuclear radiation shielding.

"To utilize the best protection available, shelter should be sought in any strong building that is accessible. Above ground, the safest locations are generally near, but not against, walls and away from doors and windows. It may be that the first indication of a nuclear attack will be a flash of light, in which case there would be a little time for taking evasive action. However, by acting promptly, a person can do something to protect himself against the effects of blast. For example, at a distance of 10 miles from a 10-megaton air burst, which is within the area where protection against blast would be effective, some 37 seconds would elapse before arrival of the blast wave. This may be sufficient time for a person to step into a nearby shelter. If

90 OCD "Blast Damage From Nuclear Weapons of Larger Sizes," Technical Bulletin Tr-8-1, February 1955 (out of print) and Department of Commerce "Facility Protection for Food Processing Plants" FG-F-3.54 US GPO 0-404-276 1970.

DAMAGE LEVEL: EXAMPLES OF DAMAGE:



Broken windows, damaged rollup doors, but generally negligible damage.

Windows and doors blown in, temporary power outage, light damage to machines, partial collapse of frame roofs. Light damage to switch gear, moderate damage to frame buildings, motors, pumps, piping, and injury to personnel hit by debris.

Moderate damage to masonry buildings, most trees blown down, exposed piping damaged, frame houses collapsed, elevated tanks damaged.

Service lines broken, extensive damage to concrete and masonry buildings. Severe damage to most reinforced concrete structures.

Total destruction, severe fire and debris condition.

Blast Threat Levels from an Air Burst

Figure 82a.

Table 42. A Few Items Damaged by Excessive Overpressures

It is helpful to list typical types of damage produced at various representative levels of overpressure. For example:

1/2 to 1 psi	Breakage of window glass.
1 to 2 psi	Light to moderate damage to transport type aircraft.
3 psi	Very severe damage, near total destruction to light industrial buildings of rigid steel framing or self-framed steel; corrugated steel structures less severely damaged.
3 to 4 psi	Severe damage to wooden frame or brick homes; can be made habitable only after extensive repair.
4 to 6 psi	Complete destruction of aircraft, or damage beyond economic or feasible repair.
5 psi	Complete destruction of wooden frame or brick homes.
5 psi	Severe battering of automobiles and trucks; tops and sides caved in, but the engines still operable.
5 psi	200 to 600 flying bits of debris, shards of glass and so on, per square yard, flying through the air at speeds of 40 to 180 miles per hour.
6 psi	Moderate damage to ships.
6 to 7 psi	Moderate damage to massive, wall-bearing, multi-story buildings.
7 psi	Possible internal injuries to human beings.
8 psi	People standing will be picked up and thrown.
9 psi	Complete destruction of railroad boxcar.
10 to 12 psi	Serious damage and sinking of all ships.
12 psi	People lying flat on the ground are picked up and hurled about.
15 psi	Possible lung injuries to exposed personnel.
20 to 30 psi	50 percent probability of ear drum rupture.

Table 43. Blast Damage by Nuclear Bomb—Air Burst[90]

No.	Item	Zone of A-damage	Zone of B-damage	Zone of C-damage	Zone of D-damage
1	(a) Ordinary buildings—typical urban complex for American cities.	Virtually completely destroyed.	Severely damaged or destroyed, buildings must be torn down.	Moderately or severely damaged; moderately damaged buildings must be vacated for repairs.	Partially damaged; buildings need not be vacated during repairs.
	(b) Reinforced-concrete or steel-frame buildings.	Buildings standing but most masonry panel walls and non-load-bearing partitions probably destroyed or displaced.	Buildings standing but many masonry panel walls and non-load-bearing partitions probably destroyed or displaced.	Interiors moderately damaged.	Interiors slightly damaged.
2	Highways and streets . . .	Impassable	Impassable	Many parts blocked by rubble and require clearing before use.	Some parts blocked by rubble and require clearing before use.
3	Elevated roads and short span bridges.	Some destroyed; approaches blocked; decks of steel-plate girder bridges may shift laterally.	Some severely damaged; bridge approaches blocked by rubble and disabled vehicles.	Moderately damaged; approaches blocked; generally usable.	Partially damaged but probably usable.
4	Vehicles: automobiles, busses, trolleys, trucks, etc.	Vehicles unusable.	Vehicles generally unusable.	Some vehicles unusable.	Most vehicles usable.
5	Railroad yards and tracks.	Some tracks blocked by damaged rolling stock and rubble.	Some tracks blocked by damaged rolling stock and rubble.	Some tracks blocked by damaged rolling stock and rubble.	Some tracks blocked by damaged rolling stock and rubble.
6	Water mains	Some mains broken especially at ground zero and on bridges.	Not damaged except on bridges.	Not damaged	Not damaged.
7	Water pipes in buildings.	Numerous breaks causing loss of pressure.	Numerous breaks causing loss of pressure.	A few breaks causing loss of pressure.	No breaks.
8	Elevated water tanks and towers.	Mostly destroyed or damaged beyond use, some substantial water towers may be usable.	Mostly destroyed or damaged beyond use; some substantial water towers may be usable.	Tanks supported by frames may fall.	Partially damaged but probably usable.
9	Sewers and storm sewers.	Some mains broken especially at ground zero.	Not damaged	Not damaged	Not damaged.
10	Large fuel gas storage tanks.	Destroyed	Probably destroyed	Possibly destroyed	Not damaged.
11	Gas mains.	Some mains broken especially at ground zero and on bridges.	Not damaged except on bridges.	Not damaged	Not damaged.
12	Gas pipe in buildings . . .	Numerous breaks	Numerous breaks	Not damaged.	Not damaged.
13	Above ground oil storage tanks.	Mostly destroyed or damaged beyond use.	Mostly destroyed or damaged beyond use.	Partially damaged; not ruptured.	Partially damaged; not ruptured.
14	Overhead electric power lines-poles, wire, and transformers.	Destroyed	Destroyed or severely damaged.	Poles, mostly usable; wires, broken by falling or flying objects; transformers, short-circuited.	Poles, mostly usable; wires broken by falling or flying objects; transformers, short-circuited.
15	Underground electric power lines.	Intact except where join overhead lines or enter transformer or power stations; some may be short-circuited if conduits flood.	Intact except where join overhead lines or enter transformer or power stations; some may be short-circuited if conduits flood.	Not damaged; some may be short circuited if conduits flood.	Poles, mostly intact; be short circuited if conduits flood.
16	Telephone poles and overhead wires.	Destroyed	Destroyed or severely damaged.	Poles, mostly usable; wires, broken by falling or flying objects.	Poles, mostly intact; wires, broken by falling or flying objects.
17	Radio and TV towers	Destroyed	Some destroyed	Some destroyed	Partially damaged but may be operable.

Table 44. Damage to Types of Structures Primarily Affected by Blast Wave Overpressure During the Diffraction Phase[12]

Description of structure	Description of damage: Severe	Moderate	Light
Multistory reinforced concrete building with reinforced concrete walls, blast resistant design for 30 psi in Mach region from 1 MT; no windows.	Walls shattered, severe frame distortion, incipient collapse.	Walls breached or on the point of being so, frame distorted. Entranceways damaged, doors blown in or jammed, extensive spalling of concrete.	Some cracking of concrete walls and frame.
Multistory reinforced concrete building with concrete walls, small window area; 3 to 8 stories.	Walls shattered, severe frame distortion, incipient collapse.	Exterior walls badly cracked, interior partitions badly cracked or blown down. Structural frame permanently distorted, extensive spalling of concrete.	Windows and doors blown in, interior partitions cracked.
Multistory wall-bearing building, brick apartment house type; up to 3 stories.	Bearing walls collapse, resulting in total collapse of structure.	Exterior walls badly cracked, interior partitions badly cracked or blown down.	Windows and doors blown in, interior partitions cracked.
Multistory wall-bearing building, monumental type; up to 4 stories.	Bearing walls collapse, resulting in collapse of structure supported by these walls; some bearing walls may be shielded enough by intervening walls so that part of the structure may receive only moderate damage.	Exterior walls facing blast badly cracked, interior partitions badly cracked, although toward far end of building damage may be reduced.	Windows and doors blown in, interior partitions cracked.
Wood frame building, house type; 1 or 2 stories.	Frame shattered so that for the most part collapsed.	Wall framing cracked, roof badly damaged, interior partitions blown down.	Windows and doors blown in, interior partitions cracked.

he is in an automobile, he might stop the car and crouch down on the car floor until the blast wave has passed. Then he should proceed to the first identifiable shelter he sees and take refuge. Under these conditions, persons finding themselves in open country should lie face down on the ground, preferably in a ditch or culvert or against a wall or building."

Thermal Radiation

The thermal radiation from a nuclear explosion does extremely serious damage to forests, dry grass areas, wooden houses, trash piles, and exposed oil pits. But it is surprising how little protection from this heat is required.

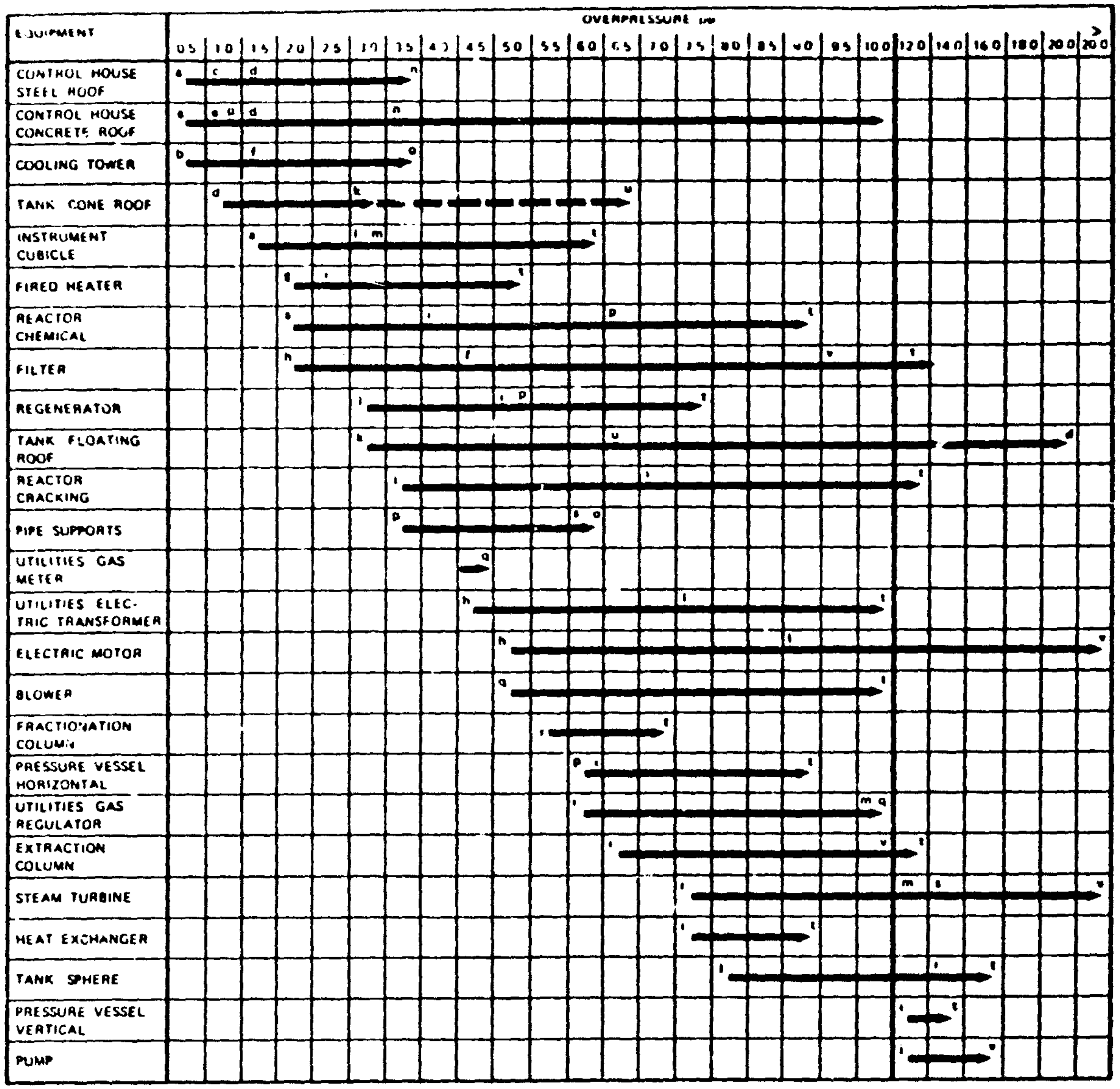
From the viewpoint of refining management, since most equipment is protected by fireproof materials, the potential damage from the thermal and ultra-violet radiations of a nuclear bomb is not as important a consideration as is blast damage protection. Good housekeeping is important and is stressed in any well managed plant. Piles of paper, exposed oil surfaces, straw piles, and uncut dry grass are not found near a modern plant, so this fraction of a weapon's yield can be covered by "good housekeeping."

While damage from heat is a great concern to exposed persons, the flashes are so quick that only the most tender or flammable material is involved. Gases from vents or exposed volatile material could be ignited under some conditions, thus setting up a tank farm fire, some of which have been mentioned. In general, our concern is mainly the protection of eyes and skin.

"The[88] direct effects of thermal radiation from a nuclear explosion on human beings are skin burns, flash burns," and permanent or temporary eye damage. The thermal radiation

Table 45. Damage to Types of Structures Primarily Affected by Dynamic Pressure During the Drag Phase [12]

Description of structure	Description of damage: Severe	Moderate	Light
Light steel frame industrial building, single story, with up to 5 ton crane capacity. Lightweight, low strength walls fail quickly.	Severe distortion or collapse of frame.	Some to major distortion of frame, cranes (if any) not operable until repairs made.	Windows and doors blown in, light siding ripped off.
Heavy steel frame industrial building, single story, with 25-50 ton crane capacity. Lightweight, low strength walls fail quickly.	Severe distortion or collapse of frame.	Some distortion to frame, cranes not operable until repairs made.	Windows and doors blown in, light siding ripped off.
Heavy steel frame industrial building, single story, with 60-100 ton crane capacity. Lightweight, low strength walls fail quickly.	Severe distortion or collapse of frame.	Some distortion to frame, cranes not operable until repairs made.	Windows and doors blown in, light siding ripped off.
Multistory steel frame office type building, 3-10 stories (earthquake resistant construction). Lightweight, low strength walls fail quickly.	Severe frame distortion, incipient collapse.	Frame distorted moderately, interior partitions blown down.	Windows and doors blown in, light siding ripped off. interior partitions cracked.
Multistory steel frame office type building, 3-10 stories (nonearthquake resistant construction). Lightweight, low strength walls fail quickly.	Severe frame distortion, incipient collapse.	Frame distorted moderately, interior partitions blown down.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
Multistory reinforced concrete frame office type building, 3-10 stories (earthquake resistant construction). Lightweight, low strength walls fail quickly.	Severe frame distortion, incipient collapse.	Frame distorted moderately, interior partitions blown down. Some spalling of concrete.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
Multistory reinforced concrete frame office type building, 3-10 stories (nonearthquake resistant construction). Lightweight, low strength walls fail quickly.	Severe frame distortion, incipient collapse.	Frame distorted moderately, interior partitions blown down. Some spalling of concrete.	Windows and doors blown in, light siding ripped off, interior partitions cracked.
Highway truss bridges, spans 150-250 ft.	Total failure of lateral bracing, collapse of bridge.	Some failure of lateral bracing such that bridge capacity is reduced about 50 percent.	Capacity of bridge unchanged, slight distortion of some bridge components.
Railroad truss bridges, spans 150-250 ft.	Total failure of lateral bracing, collapse of bridge.	Some failure of lateral bracing such that bridge capacity is reduced about 50 percent.	Capacity of bridge unchanged, slight distortion of some bridge components.
Highway and railroad truss bridges, spans 250-500 ft.	Total failure of lateral bracing, collapse of bridge.	Some failure of lateral bracing such that bridge capacity is reduced about 50 percent.	Capacity of bridge unchanged, slight distortion of some bridge components.



Code

a. Windows and gauges break
b. Louvers fall at 0.3–0.5 psi
c. Switchgear is damaged from roof collapse
d. Roof collapses
e. Instruments are damaged
f. Inner parts are damaged
g. Brick cracks
h. Debris-missile damage occurs
i. Unit moves and pipes break
j. Bracing fails
k. Unit uplifts (half-filled)
l. Power lines are severed
m. Controls are damaged
n. Block walls fail
o. Frame collapses
p. Frame deforms
q. Case is damaged
r. Frame cracks
s. Piping breaks
t. Unit overturns or is destroyed
u. Unit uplifts (0.9 filled)
v. Unit moves on foundation

Figure 83. Blast Overpressure Effects on Vulnerable Refinery Parts[91]

Source: SRI

is received in two pulses; therefore, if an individual is caught in the open or is near a window at the time of a nuclear explosion, evasive action to minimize flash burn injury should be taken before the maximum in the second pulse. Under the slower moving blast wave, the second thermal maximum arrives in less than one to about three seconds after the first pulse depending on the size of the weapon. Evasive action must be fast, but any opaque object interposed between the fireball and exposed skin will give some protection.

"Thermal radiation may start fires at considerable distances beyond the blast-damaged area. Appropriate fire control action may be directed along these lines: (a) reduction of potential ignition points, (b) shielding of flammable materials, (c) rapid extinction of small ignitions to prevent formation of large fires, and (d) prevention of fires spread by dispersal of buildings in urban areas."

Protection from Heat—For protection against thermal radiation, flammable structures should be painted white or silver. Dark material absorbs heat rays and increases the chance of ignition. A thin reflective coating such as tin or aluminum foil which can reflect the heat rays is equivalent to about one-half inch of asbestos insulation. A white sheet, a newspaper, a board fence, or heavy clothing give measurable protection.

Fallout Protection

Much has been said already about dangers connected with exposure to radioactive fallout. It is reviewed here as a damaging effect of the general lack of fallout shelters in most refineries. Wind currents will circulate and scatter fallout particles over a large area after an attack. Plants far away from a blast area could within a few areas be shut down. Chances are that they would remain down for several weeks because of radioactive contamination in the plant grounds.

Civil Defense authorities recognize that as long as we protect lives, we can retaliate and rebuild. Protection from radioactive fallout is an absolute essential if our corporate structure and industry are to be maintained after a nuclear attack. Without adequate fallout shelters, a few ground blasts with nuclear weapons could kill millions of people in affected areas. It could in itself completely disrupt our industrial activity. It is estimated that from 40 to 120 million lives can now be saved with shelters when under an attack as compared to having no shelters. At present time there is shelter capacity for most of our population if they are able to get to a place in time, but the need appears *urgent for essential industry to be able to protect workers' lives from fallout and still be able to operate.* Who can do this?

One place to start is in the control house. As one builds it to withstand explosions likely to occur at some time in a refinery or petrochemical plant, at relatively small additional expense one can build in *protection factor* so at least one haven of safety exists where systems can still be controlled. By increasing the mass of the walls and roof, by extending the building size, protection factor is increased. In a concrete block building, sand filled into the holes of the blocks during construction increases the mass of the wall; reinforcing bars in the walls and roofs increase its blast resistance. The more dense the walls and roof, the better the protection from fallout. See Figure 84.

Civil Defense has available many publications to assist industry in protecting itself against radioactive fallout. The construction of shelters, the use of existing buildings as shelters and their management when under attack are covered in these publications. This is all a part of a National Shelter Plan.

Much has been accomplished by the National Shelter Plan; procedures for seeking buildings capable of providing shelter for groups is a constant effort by Civil Defense workers. Those buildings holding at least 50 people and having a protection factor of 40 are being stocked by the Federal Government with food, radiological monitoring, and sanitary and medical supplies. The whole program is outlined as follows:

Nationwide Fallout Shelter System

1. *National Shelter Program*
   a. Identify shelter spaces.
   b. License shelters.
   c. Mark shelters.
   d. Stock shelters.
   e. Locate improbable shelter spaces.
   f. Keep shelter data current.
2. *Community Shelter Planning (CSP) Program*
   a. Allocation
   b. Emergency information readiness
   c. Identification of shelter deficits
   d. Development of shelter
   e. Updating emergency plans
   f. Official adoption of Community Shelter Plan
3. Provide additional shelter spaces (Federal bldgs. etc.).
4. Encourage business, industry, and the public to provide shelters.
5. Plan for effective use of shelters, including training management staffs.

Fallout protective shelter usually cannot give complete protection from damaging rays, but can considerably reduce the rate of exposure. One can see the many variables involved in predicting exposure level at any one location. The type of burst, size of bomb, strength of wind, composition of the bomb, the massiveness, width and height of the building in which protection is sought, and other factors are items of consideration when estimating potential exposure to radioactive rays. Figure 85 shows that the inner part of a large building is farily safe from fallout radiation provided a filtered air supply is available.

Radiation reaches a person sheltered in a building from particles on the roof as *direct* radiation; from the ground as direct, reflected from the sky as *skyshine* and from deflected rays coming through a wall as *scatter*. This is shown in Figures 86 and 87.

A *protection factor* (PF) is a comparison of exposure of a person inside a building and to one on the outside. A structure that reduces radiation by a factor of 40 gives 40 times the protection to a person inside than one would have

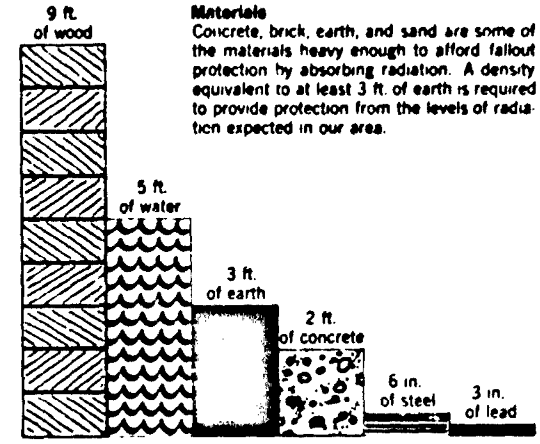


Figure 84. Density of Materials and Relative Protective Value

Fallout Radiation Effects

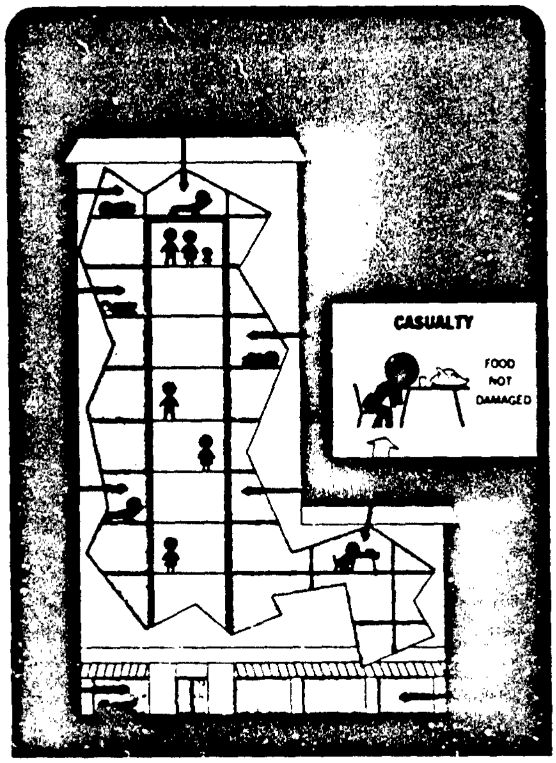


Figure 85. People in the Inside Rooms Have Greater Protection[92]

---

92 Dep't of Commerce- Iron and Steel Industrial Defense Planning Manual- Coop with Dep't of Defense- October 1965.

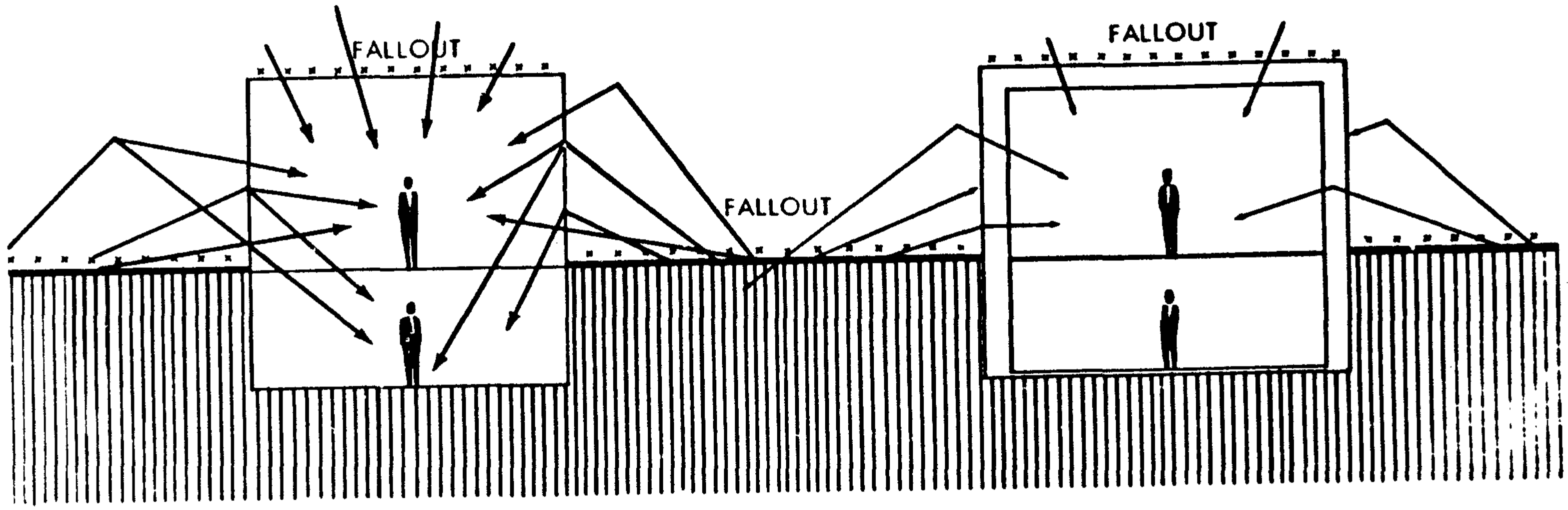


Figure 86. Basic Principles of Fallout Protection in New Construction[93]

Increase thickness of walls and roof – use appropriate basement areas – apply cost-reduction design techniques.

93 Office of Civil Defense- [illegible] Shelter in Industrial, Commercial, and Business Buildings- April 1966.

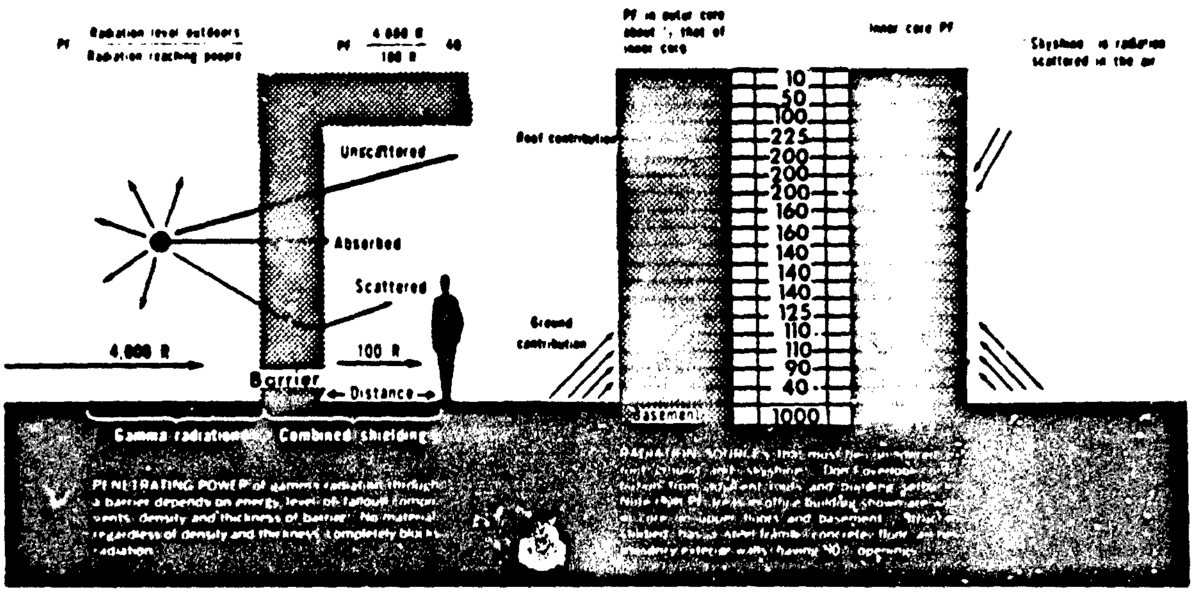


Figure 87. Protection Factors Applied to Building Core Locations

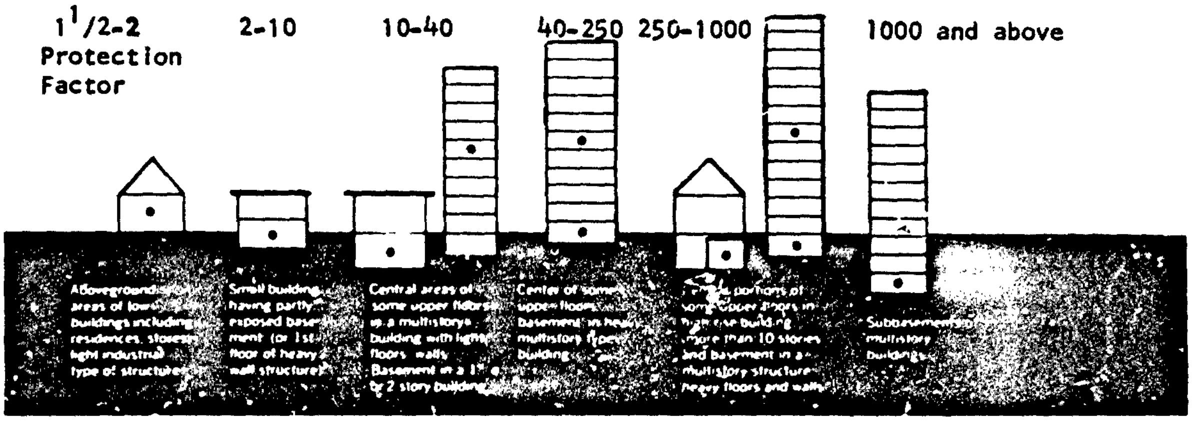


Figure 88. Typical Shelters in Various Types of Buildings

Likely Shelter Locations in any building are those offering highest protection factors. Illustration below gives a general idea of the relative protection found in common structures. Use it as a guide only, to estimate protection against fallout. The PF values listed may be conservative, being based on isolated structures.

Source: Fallout Shelters TR-39 OCD

on the outside. Inside he would receive 1/40 or 2-1/2% of the outside exposure. Protection is obtained by *barrier shielding*, dense walls, and by *geometric shielding* when one can place himself out of the rays of the radiation. Figures 87 and 88 show this concept. Buildings that have been surveyed and approved as fallout shelters by Civil Defense authorities are marked with the familiar yellow and black Fallout Shelter sign. The operation and management of the shelter during an attack are a part of the plans.

There is no requirement that the general public be allowed sanctuary in a plant. In fact, extremely strict security measures will be effected at an early stage, possibly even prior to an attack, if possible. Employee protection is essential for several reasons:

1. Because of the likely short warning of an attack, employees cannot go home. The time would be too short, and the streets will be plugged with traffic.

2. The petroleum industry is vital to any war effort, so

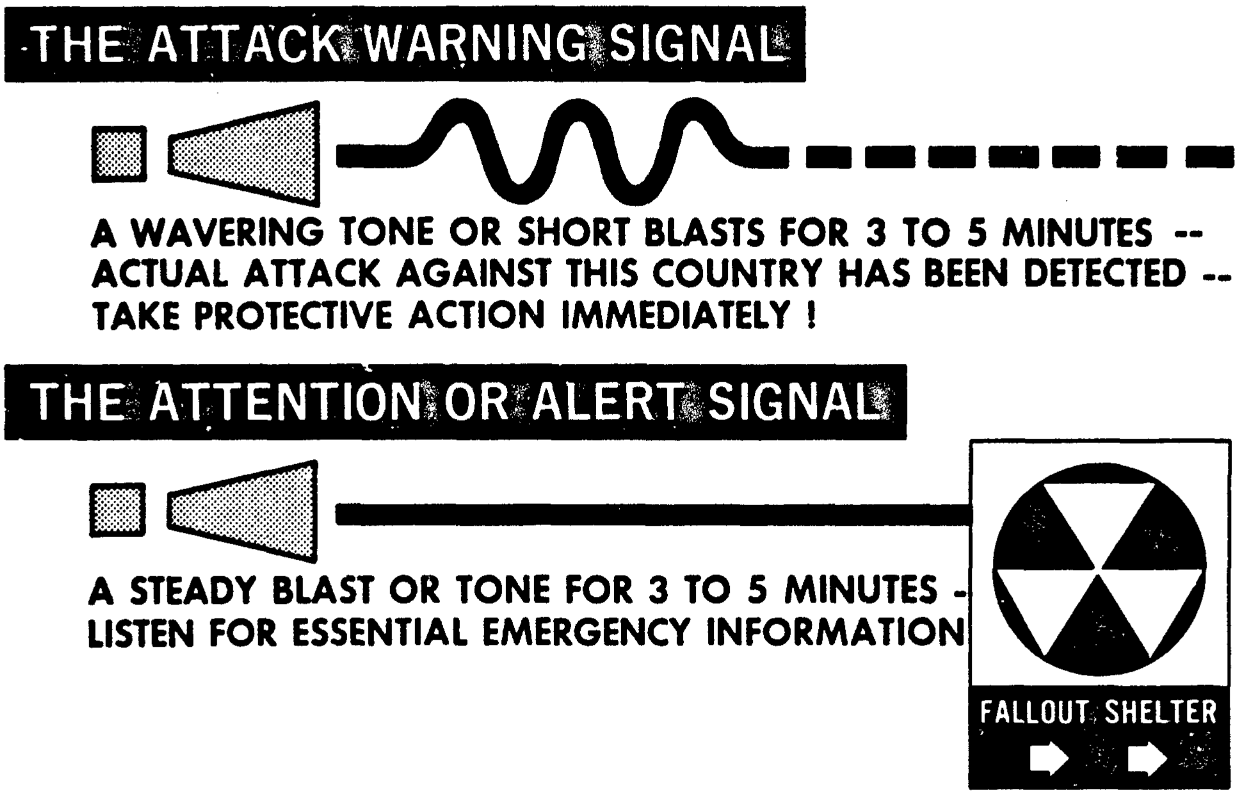


Figure 89. OCD Form 496, Mar 67

operations must continue if at all possible in all emergencies.

3. Since radiation cannot be felt, there will be those who will expose themselves unless previously trained not to do so, and they must be given reasonable protection from radiation also.

Family protection arrangements are essential not only to protect these lives, but also to give the refinery operator peace of mind so he can continue his work under protection in the radioactive environment.*

The fixed responsibility for emergency planning in each company needs to be assigned to someone or a group. Next, a survey and study of potential problems related specifically to the company's installations' needs must be evaluated. *Then positive action is essential.* The usual fallout shelter needs to be as substantial as practicable. It is better to be blast resistant, but many good shelters are not. In a refinery, it is good management to build to protect against possible explosions that could occur from the process. It is also good management to plan for national emergency and be organized to operate under wartime conditions.

* A recent publication "Housing With Shelter—Dual-Purpose Residential Fallout Protection" (HUD-180-S) is now available from the Superintendent of Documents, U.S. Gov. Printing Office, Washington, D.C. 20402.

Warning

The National Warning System (NAWAS) has three general centers. From these, other local centers are warned by voice communication of impending danger. The entire country is linked together in a gigantic communication net, so that each local government is alerted when the time comes. Each local area must have its warning system. Sirens or horns are used.

The alert signal is a steady blast for 3 to 5 minutes. This is a call to attention. Turn into a local broadcast station for instructions.

The *Attack Warning* signal is a wavering tone or many short blasts of 3 to 5 minutes over a 3 to 5 minute period. This warning requires instant response. Find as safe a spot as possible, for an attack is indicated. Copies of Figure 89 should be prominently displayed throughout all offices and plants so that everyone knows the signals and knows what to do.

Certainly this country will never start a nuclear war, and because of our size and preparations, no country exists that could completely knock out our retaliatory capability by some preemptive attack. Figure 90 shows four reasons for this:

1. Interception will destroy some missiles before they land.

2. The number of important targets in this country are so great that a choice must be made.

3. Long range missiles are not accurate enough to hit exactly on target.

4. Many misfires will be experienced.

It is for these reasons as well as those mentioned before that radioactive fallout created by an enemy attack is a major fear and the easiest to protect against. The petroleum fuels industry is *not prepared to cope with this problem and needs to get with it.*

One factor often not given serious thought is the possibility that other countries across the ocean who have nuclear potential might decide to shoot it out. If such an exchange of nuclear weapons took place, the upper atmosphere could become seriously contaminated, enough so that the continuity of industry in this country on a "business as usual" basis would be impossible. *Those prepared will be able to do so.*

Summary—A large nuclear blast any place in the world could have some damaging effects on our industry because of a radioactive fallout threat. No country can prevent us from retaliating in kind for a surprise attack, but the more protection available for people, the greater will remain our striking force.

It is important that all industry prepare itself to operate under conditions of radioactive fallout. Figure 91 summarizes some of the advantages of the entire system.

LIFESAVING POTENTIAL OF IMPROVED STRATEGIC DEFENSE (Figure 91)

This panel depicts the effectiveness of various defensive postures in terms of lives saved. The data are taken from Department of Defense studies, but the assumptions used here are more extreme. All damage limiting defensive systems are measured against the pessimistic assumption that an extremely severe attack occurs against population targets.

No Shelter. In the absence of an effective shelter program for the protection of the population, about 144 million people would become fatalities.

Full Fallout Shelter (I). On the assumptions that 10% of the people would fail to use available shelters and others would improperly use the shelters (e.g., late entrance and early exit), the full fallout shelter program would save 48.5 million people. It was also assumed that there would be an increasing population shift to urban areas. Certain offsetting factors were not included for lack of adequate data; the blast protection afforded by fallout shelters, buildings, terrain and other local characteristics; fatalities from fire spread beyond the impact area.

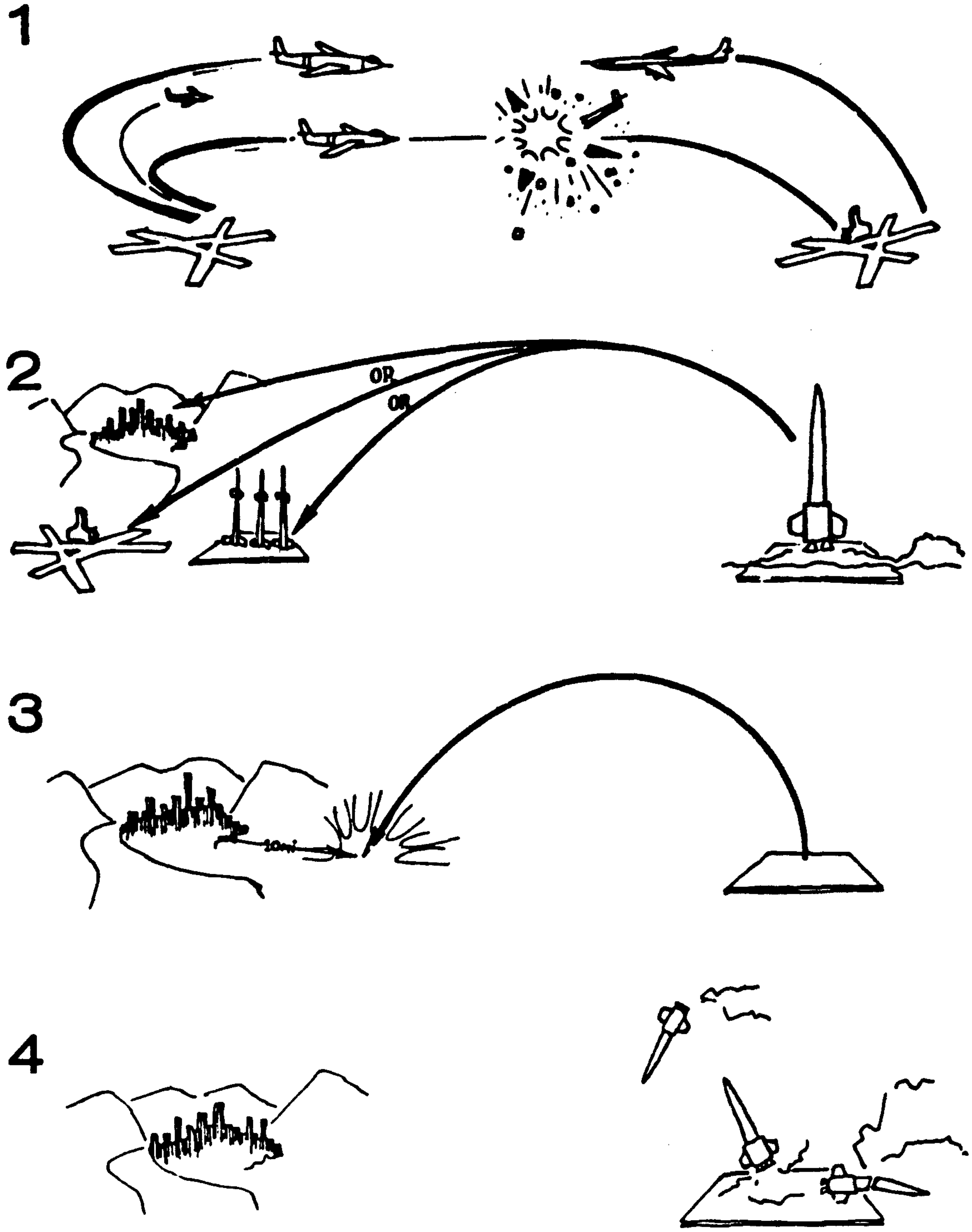
To date at total program cost of about $800 million (FY 1962-1967) over 160 million fallout shelter spaces have been identified. Projecting the present program through FY 1975 would result in fallout shelter for 1/2 to 2/3 of the estimated 1975 population at a cost of about $800 million additional.

Blast Shelter (II). This posture includes 30 psi blast shelter in the central cities of the 100 largest metropolitan areas, 10 psi blast shelter in the suburban areas surrounding these cities, and fallout shelter for the rest of the country. Approximately 25 million lives would be saved over the full fallout shelter posture at an additional cost of approximately $19.0 billion.

Ballistic Missile Defense (III). Provides protection for 22 cities at a 5-year cost of $18.0 billion. (Arbitrarily selected median of various studies of hypothetical systems ranging from 20 to 25 cities defended and costs of $16 to $20 billion.) This posture would save 27.8 million people in addition to those saved by the full fallout shelter posture.

This system must be combined with the full fallout shelter system as an enemy could detonate a weapon upwind, outside of the defended areas, and kill those without fallout shelter in the ABM protected cities.

All Systems (IV). All of the preceding postures added together could save a total of almost 100 million lives.



(After Civil Defense, USA.)

Figure 90. Four Reasons Why an Enemy Will Not Be Able to Hit All Targets in the United States

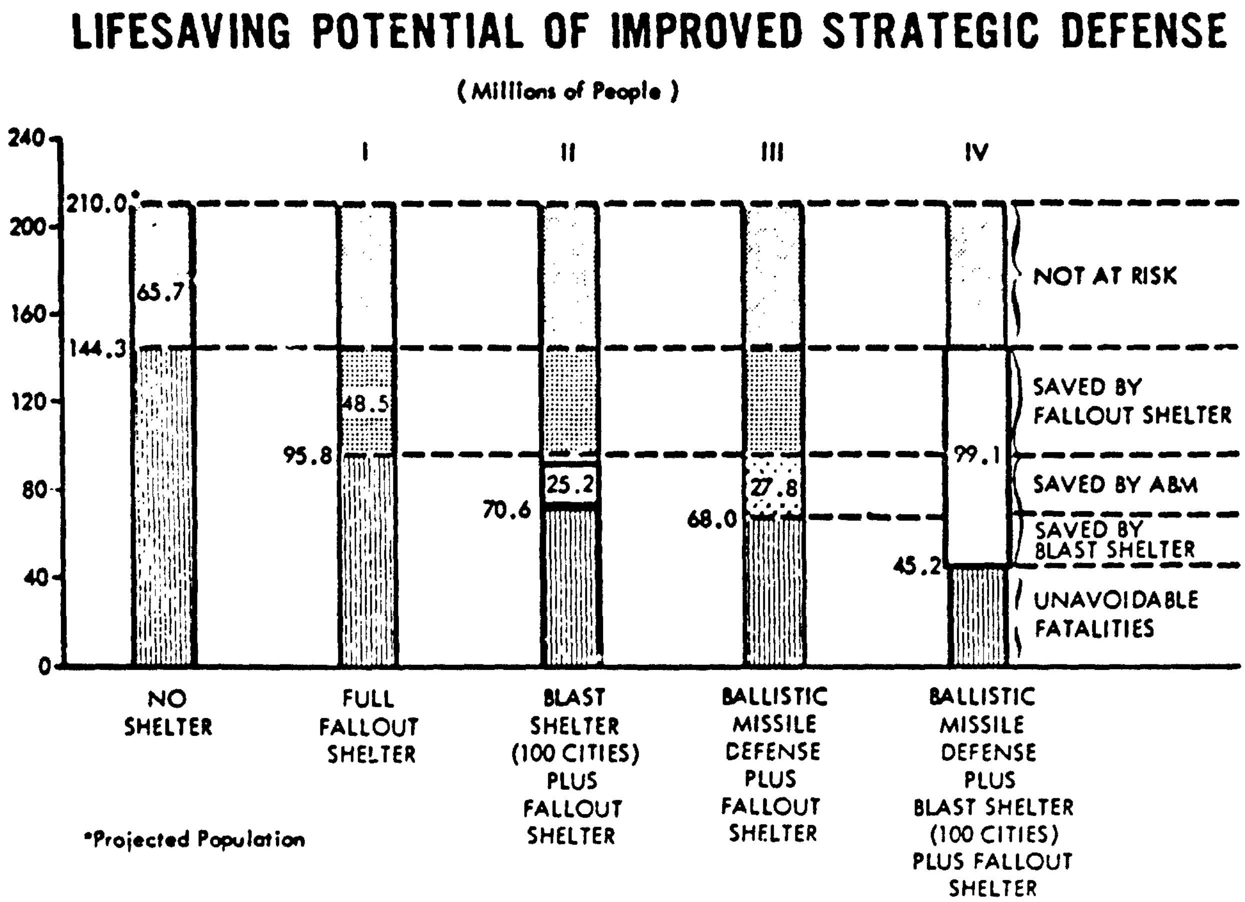


Figure 91. Lifesaving Potential of Improved Strategic Defense

INDUSTRIAL SURVIVAL PROGRAM

WHY?

TO SURVIVE THE EFFECTS OF ATTACK OR OTHER DISASTER.

WHERE?

WITHIN INDUSTRIAL PLANTS, INSTITUTIONS, AND OTHER LARGE FACILITIES.

WHO?

Emergency Planners, Civil Defense Coordinators, and Security Officials in Industry, —Should Do These Things In Cooperation With Local Government Officials:

WHAT?

1. ORGANIZE AND PLAN FOR SELF-PROTECTION—by enlarging such services as communications, the plant fire brigades, medical and first-aid facilities, rescue teams, and warden, welfare, and police groups.

2. SET UP SECURITY PLANS—for protection against sabotage and espionage.

3. PROVIDE SHELTERS—by designating safe areas in existing buildings and by including protective features in the design of new construction.

4. PLAN FOR EVACUATION—including the reception and care of employees in safer areas and their return to their home communities and jobs following attack.

5. PLAN FOR CONTINUITY OF MANAGEMENT—including the selection and equipping of alternate company headquarters, the establishment of personnel succession lists, and the development of emergency financial arrangements.

6. PROTECT VITAL RECORDS AND DOCUMENTS—by duplication and storage in vaults or areas safe from attack.

7. PLAN FOR EMERGENCY REPAIR AND RESTORATION—by establishing a system for quickly assessing damage and for restoring production, including alternate arrangements for manpower, equipment, warehousing, and supply.

8. ESTABLISH INDUSTRIAL MUTUAL AID ASSOCIATIONS FOR CIVIL DEFENSE—by joining up with other neighborhood industrial plants and facilities to provide assistance to each other in the form of equipment, materials, or personnel in time of emergency and disaster.

9. DECONCENTRATE PRODUCTION—by being sure that critical items are manufactured in more than one place.

10. DISPERSE NEW INDUSTRIAL PLANTS—employ the simple military measure of using space for defense of industrial plants against attack. Industrial dispersion will also result in reducing the vulnerability of our cities to attack by making them less attractive as enemy targets.

HOW?

See your local civil defense director. Use this kit which contains general informaton on civil defense, and detailed information on how to carry out civil defense planning and organization within industrial plants, hospitals, schools, office buildings, department stores, and other institutions and large facilities.

WHEN?

Do it now—After the bombs fall it will be too late!

GPO 805068

Chapter X

NATIONAL PLAN FOR EMERGENCY PREPAREDNESS

Introduction

From the dawn of history to the present, most nations no matter how weak or how powerful have at one time or another faced an adversary, another country who sought to force its wishes on those people of the area. There are very few times of record, if any, that the nation being attacked was not peace loving, having no desire for armed conflict. Yet the differences between nations in ideals, living conditions, economy and political zeal have made war and force a common method of aggression. The inalienable right of a people is to live as they wish to live without being forced to accept an ideology of another type of government.

Civil emergency planning has been carried out continuously in the United States since the 40's, but the form taken by the plans has gone through considerable evolution. The petroleum industry was organized for operation under conditions of war on previous occasions. The formation of the Petroleum Administration for War during World War II and later the Petroleum Administration for Defense, (PAD), in October 1950 was a forerunner of the current emergency organization, the Emergency Petroleum and Gas Administration (EPGA).

The Office of Emergency Planning[95*] published a plan in December 1964 that further set out preparation guidelines for use of the agencies of the Federal Government, states, counties, and cities preparing for the time of a war. The handling of emergencies due to peacetime disasters, an Office of Emergency Planning and Civil Defense function, is included in other documents, most of which have already been cited. The National Plan replaced a previous plan of 1958 entitled "The National Plan for Civil Defense and Defense Mobilization."

In introducing the precepts of the National Plan, President John F. Kennedy made the following statement: *"Until all men learn to live in peace with one another, until the threat of war, deliberate or accidental, is forever dissolved, it will be necessary for the United States to be ready to defend itself—its ideals and systems, its people and resources—against both annihilation and attrition, with every means at its disposal. In this area of global mobility and global unrest, of massive population and industrial concentrations and massive means for their destruction, this Nation's defenses cannot lie solely with its military forces and weapons. Defense has become a direct responsibility of all levels of government and of all the people. Intrinsic parts of total defense, vital to its success, are the protection of life and property against the effects of an attack and the provision of survival and recovery means under all kinds of hostilities.*

"These are the subjects of The National Plan for Emergency Preparedness. *I commend it to the attention of all who share in these responsibilities."*

Types of Contingencies

The emergency planning of the nation needs to be quite broad in its coverage. In general, three types of contingencies are considered: international tension, limited war, and general war which includes nuclear war. Since events could progress rapidly through the first two contingencies, the thrust of emergency planning must include complete preparedness for an all-out nuclear confrontation.

Emergency planning extends through all major segments of our government. Key men of industry and government are organized to exercise emergency direction of all critical facets of our economy. Each group trains regularly so as to be able to function with dispatch if suddenly called into action.

During the stage of *international tension,* it is not considered necessary to exercise strong government control on materiel or on the economy, even though some important items could become limited in their supply.

The amount of control could change to a degree in the case of a *limited war,* depending upon the confines of it or upon the size of its involvement. Some mobilization measures could be required, particularly in the control of our natural resources. Certainly all emergency organizations would be alerted, and some might be ordered into full operation by proper authority.

In the case of a *general war,* contingency plans call for all emergency organizations to be activated. Comprehensive emergency measures would be immediately put into effect, and an all-out effort would be made to minimize confusion that might accompany a direct attack on our nation. There will be no time to organize for national survival when a general war is declared. *Now is the only time to make plans and prepare for such an eventuality.*

The National Plan for Emergency Preparedness quite specifically spells out Federal governmental agencies' responsibilities.

Basic Policies

During and immediately after a period of a nuclear blast, the main thrusts of our efforts are *survival* and *recovery.* The saving of lives and property is of extreme importance, as is the preservation of our retaliatory abilities and the giving of essential aid to our allies. The conservation and management of all our resources will be of great concern. Fundamentally, individual rights will be protected as will the political, economic and social structure of the Nation. This precept is stated in the National Plan as follows[95]

95 Office of Emergency Planning "The National Plan for Emergency Preparedness" (Su't. of Documents- 75¢) Office of Emergency Planning December 1964

* Office of Emergency Planning now in 1969 called the Office of Emergency Preparedness. Most currently available literature carries the older title.

"Emergency preparedness is directed not only toward physical survival, but also toward preservation of the basic values of the Nation. Consequently every effort should be made to:

"Protect the free exercise of constitutional and other basic rights and liberties under emergency conditions, insuring that any restrictions imposed on the exercise of rights and liberties during a national emergency be limited both in scope and duration to the minimum required by the circumstances.

"Preserve equitably representative constitutional government.

"Maintain law enforcement and judicial proceedings in accordance with established and accepted practices and procedures, developing emergency codes and emergency systems of civil justice as necessary to prevent the arbitrary exercise of the police power.

"Continue a basically free economy and private operation of industry, subject to government regulation only to the extent necessary to the public interest."

In order to be able to preserve our freedom in time of emergency, it becomes necessary for all citizens to prepare for life under war time disruptions. Starting from the home and local industry through the smallest increment of local government, through the county, through the state, and through the Federal Government, each segment must make its plans and coordinate them with the National Plan. The Federal Government will exercise control of direction and coordination, but will not take over state and local authority unless such breaks down under pressure, and then only for as long a time as is necessary to restore order and local authority. The reverse is equally true.

Basically, the reasons for the entire emergency program is outlined as follows:

Mitigation of Damage
- Reduction of vulnerability
- Provision of essential community services

Economic Survival and Recovery
- Provision of essential resources
- Management of resources
- Economic stabilization

Institutional Survival and Recovery
- Maintenance of civil order
- Continuity of government
- Protection of rights

The Office of Civil Defense with some exceptions serves as an over-all administrator of the Federal Civil Defense Act of 1950. The Reorganization Plan No. 1 of 1958 transferred all of the statutary functions of the Federal Civil Defense Administration and Administrator to the President. On July 20, 1961, the President issued an Executive Order 10952, which assigned most civil defense responsibilities to the Secretary of Defense, except those emergency powers contained in Title III of the Act. Title III gives the President authority for condemnation of buildings, facilities, and materials when necessary for a declared civil defense emergency.

The main thrust of the Office of Civil Defense effort in time of war is to save property and sustain life. Other departments and agencies of the Federal Government have assigned responsibilities related to their function in normal times.

The Office of Emergency Preparedness (OEP) assists the President in coordinating emergency preparedness activities of the Federal Government. In time of war, the OEP duties will be absorbed by a planned emergency agency, the Office of Defense Resources. Its duty is to coordinate over-all central resource management functions toward established objectives.

The two programs of the Office of Civil Defense and the Office of Emergency Preparedness[96] are compared in Table 46.

It is clear that almost all functions of government become involved in the preparedness program. The responsibility for the development of emergency programs and for implementing them in time of war is shown in Table 47.

Executive Reservists

It is the responsibility of most government agencies to "develop and execute educational and training programs in support of their assigned emergency preparedness functions, including National Defense Executive Reservists".[95]

This trained group in time of war will provide direction for and coordinate the economy and essential industry. It is not the purpose of the emergency reservists to operate individual plants or take over functions of elected government. Existing managements of all industry are expected to continue in their management functions.

"The objective of this program is to assure the effective use of essential resources, including military support, for civil defense in a national emergency. The Federal Government would not take over or operate privately-owned enterprises except as required by the national security.

"The program operates within the context of the OEP-OCD Memorandum of Understanding (January 14, 1964), which draws the distinction between 'primary' and 'secondary' resources. (The OEP *Example of a State Plan for Emergency Management of Resources* more specifically describes Federal-State resource responsibilities in particular resource fields and provides planning guidance to the States.) Primary resources (generally, interstate wholesale stocks and manufacturers' inventories which have national or major interstate use) are under the jurisdiction of the Federal resource agencies in accordance with priorities and control program decisions of the Director of OEP or its successor agency. Secondary resources (generally, retail stocks and wholesale stocks for interstate use) are under the jurisdiction of State and local government in accordance with guidance and assistance from Federal agencies.

"In addition, a State would direct the use of primary resources in the State if the Federal Government were unable to do so."[95] See Figure 92.

---

96 Staff College Office of Civil Defense- Civil Defense, U.S.A.- Unit 5- Department of Defense- Office of Civil Defense- SM 5.5 June 1968.

Table 46.[96] A Comparison of Civil Defense Responsibilities of:

Office of Civil Defense

a. Develop and execute:
   A fallout shelter program-
   A chemical, biological, and radiological warfare defense program-
   All steps necessary to warn or alert Federal military and civilian authorities, state officials, and the civilian population-
   All functions pertaining to communications, including a warning network, reporting to shelters and communications between authorities-
   Emergency assistance to state and local governments in a post-attack period, including water, debris, fire, health, traffic police, and evacuation capabilities-
   Protection and emergency operational capability of state and local government agencies in keeping with plans for the continuity of government-
   Programs for making financial contributions to the states (including personnel and administrative expenses) for civil defense purposes-
b. In addition to the foregoing, the Secretary shall:
   Develop plans and operate systems to undertake a nationwide post-attack assessment of the nature and extent of the damage resulting from enemy attack and the surviving resources, including systems to monitor and report specific hazards resulting from the detonation or use of special weapons-
   Make necessary arrangements for the donation of Federal surplus property in accordance with section 203 (j) (4) of the Federal Property and Administrative Services Act of 1949, as amended (40 U.S.C. 484 (j) (4), subject to applicable limitations-

Office of Emergency Planning *

a. The Director of OEP shall advise and assist the President in:
   Determining policy for- planning, directing and coordinating, including the obtaining of information from all the departments and agencies, the total Civil Defense program-
   Reviewing and coordinating the Civil Defense activities of the Federal departments and agencies with each other and with the activities of the states and neighboring countries in accordance with Section 201 (b) of the Act-
   Determining the appropriate civil defense roles of Federal departments and agencies, and enlisting state, local and private participation, mobilizing national support, evaluating progress of programs, and preparing reports to the Congress relating to civil defense matters-
   Helping and encouraging the States to negotiate and enter into interstate civil defense compacts and enact reciprocal civil defense legislation in accordance with section 201 (g) of the Act-
   Providing all practical assistance to states in arranging, through the Department of State, mutual civil defense aid between the states and neighboring countries in accordance with section 203 of the Act-
b. The Director of OEP shall also:
   Develop plans, conduct programs, and coordinate preparations for the continuity of Federal governmental operations in the event of attack-
   Develop plans, conduct programs, and coordinate preparations for the continuity of state and local governments in the event of attack, which plans, programs and preparations shall be designed to assure the continued effective functioning of civilian political authority under any emergency condition-

* Explanatory note: Section 601 (14) of Executive Order 11051 of September the 27th, 1962 (27 F.R. 9683)- amended Executive Order 10952 of July 20th, 1961, by amending each reference to the Office of Civil and Defense Mobilization and to the Director of the Office of Civil and Defense Mobilization to refer to the Office of Emergency Planning and to the Director of the Office of Emergency Planning respectively. The asterisk is used throughout the text to indicate this change in names. This agency is now called the Office of Emergency Preparedness.

It is the responsibility of private industry management to prepare its staff for emergency operations. It needs to devise plans, assign emergency responsibilities, train employees in emergency operations, and test periodically the effectiveness of their plans. Most alert management already has made such plans.

In making emergency plans, the plant manager can enlist the assistance of local civil defense directors and the local field representatives of certain Federal agencies to which the President has assigned civil defense duties by Executive Order. Such plans will be discussed later.

The following listing[97] indicates the types of facilities for which the various Federal agencies have such responsibilities:

97 Office of Civil Defense - Industrial Civil Defense "Federal Civil Defense Guide" Part F. Chapter 3, August 1966

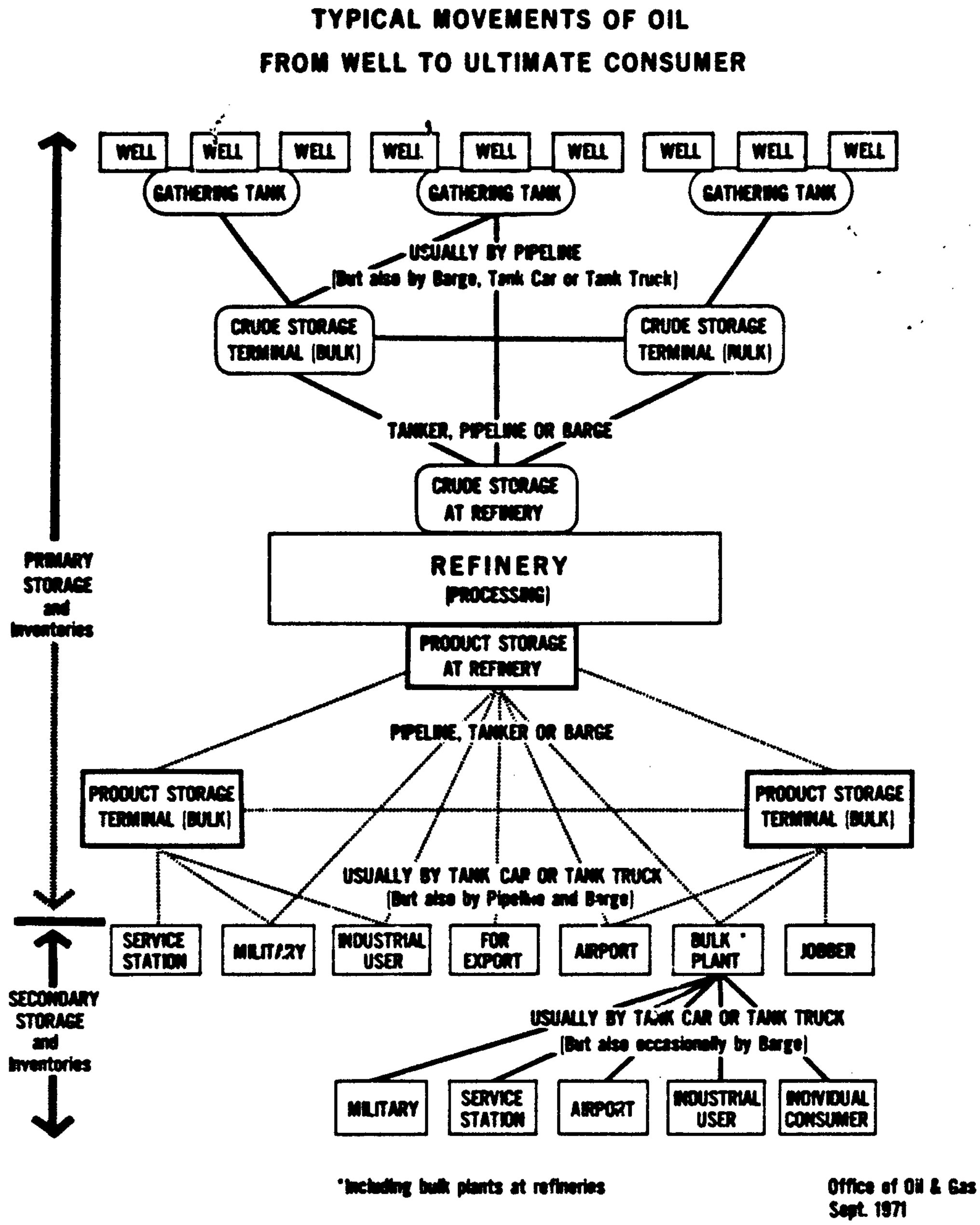


Figure 92. Typical Movements of Oil From Well to Ultimate Consumer[100]

Federal Agencies	Scope of Facility Protection Responsibility
Department of the Interior	Facilities producing and distributing electric power, petroleum and gas, solid fuels, and minerals.
Department of Agriculture	Food processing, farm equipment, fertilizer, rural civil defense.
Department of Commerce	Manufacturing facilities (other than those indicated above).
Department of Health, Education, and Welfare	Drug manufacturing and distributing facilities; hospitals, clinics; schools, welfare institutions.
Federal Aviation Agency	Civil airports, civil aviation operating facilities, civil aviation services.
Interstate Commerce Commission	Railroads, motor carriers, inland waterways; domestic surface transport and storage facilities.
Federal Communications Commission	Common carriers (wire or radio) services; broadcasting facilities.
General Services Administration	Federally occupied buildings.
Federal Reserve System Federal Loan Bank Board	Banks, savings and loan associations, and other financial institutions.
Farm Credit Administration	
Federal Deposit Insurance Corp.	
Tennessee Valley Authority	TVA power production, flood control, and waterway facilities.
Veterans Administration	Veterans facilities

The National Plan for Emergency Preparedness[95] defines the work of each government agency in pre-attack conditions and further relates how each should work as a team to re-establish normalcy after an attack.

"Over thirty departments and agencies are involved in carrying out the emergency functions in management resources."[98] Some are listed in Table 47.

The EPGA- The petroleum industry is a Department of the Interior responsibility. The Office of Oil and Gas has an extensive Executive Reserve program to man the standby Emergency Petroleum and Gas Administration (EPGA). Key men of the industry have pledged their talents and readiness to serve as government employees in time of an emergency. Assignments to important positions have been made, and these are revised constantly as changes are required. A National Headquarters, Regional offices, gas group offices as well as State Managers have been established. There are other similar emergency organizations serving other functions of government. For example, manpower is served by the National Manpower Agency (NMA). Industrial production and business were until recently served by the Business and Defense Services Administration (BSDA). This organization is now the Bureau of Domestic Commerce. Electric power is served by the Defense Electric Power Administration (DEPA). Minerals and solid fuels are served by Emergency Minerals Administration (EMA) and the Emergency Solid Fuels Administration (ESFA). During an emergency, if any conflict in demands occurs between groups that cannot be readily adjusted, the Office of Defense Resources (ODR), (The Office of Emergency Preparedness in peace time) resolves the situation.

Defense regions are indicated in Figure 23 of Section I and are shown in more detail for reader's convenience in Figure 93. The eight regional offices are indicated. Note Natural Gas has nine groups, but a plan is underway to create ten regions. The regional offices of OEP, OCD, and EPGA can serve as headquarters in case the country becomes divided. Most centers' underground facilities have both blast and fallout protection built in. It is here that some members of the Executive Reserve will work in time of war.

Table 47. Defense Planning of Responsibilities of Government Agencies

Program	Agency with Primary Responsibility
Basic Principles	Office of Emergency Preparedness*
Civil Defense	Department of Defense
Welfare	Department of Health, Education, and Welfare
Health	Department of Health, Education, and Welfare
Manpower	Department of Labor
Transportation	Department of Transportation
Telecommunications	Office of Emergency Preparedness
Food	Department of Agriculture
Water	Department of the Interior
Fuel and Energy	Department of the Interior
Minerals	Department of the Interior
Fisheries**	Department of the Interior**
Resource Management	Office of Emergency Preparedness
Economic Stabilization	Office of Emergency Preparedness
Production	Department of Commerce
Housing	Housing and Home Finance Agency
Government Operation	Office of Emergency Preparedness

* Once called Office of Emergency Planning

** Commercial Fisheries - Department of Commerce (Fall 1970)

98 Emergency Advisory Committee for Natural Gas "Emergency Operations Guide for the Natural Gas Transmission and Distribution Industry" U. S. Department of the Interior, Office of Oil and Gas, Oct. 1967.

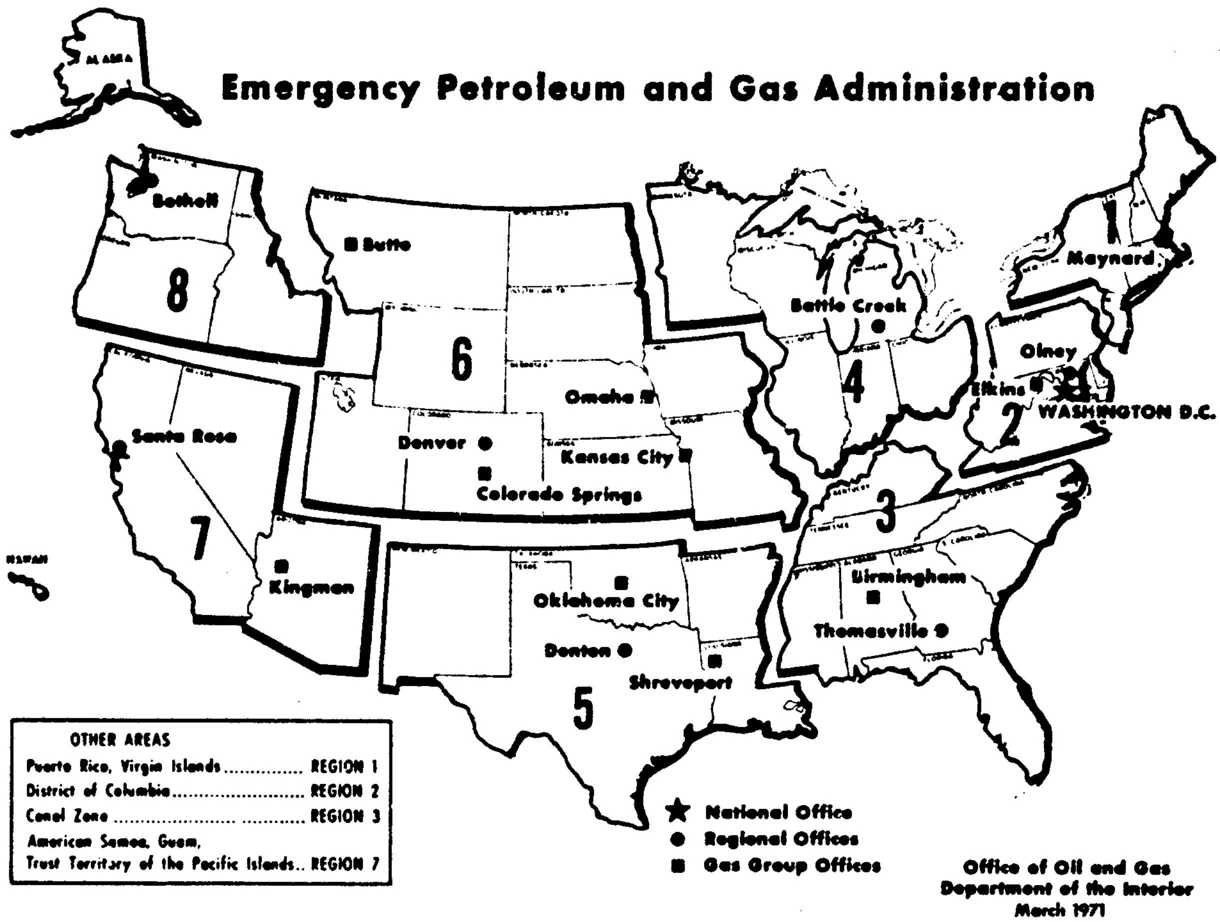


Figure 93. Map Illustrates Boundaries for Office of Emergency Planning—Office of Civil Defense and EPGA Regions [98] *

	Office OCD-OEP	EPGA - Regional	EPGA - Gas Group
Region I	Federal Regional Center Maynard, Mass. 01754	Maynard, Mass.	(I) Birmingham, Ala.
Region II	Olney, Md. 20832 Hdq. Washington, D.C.	Olney, Md. Hdq. Washington, D.C.	(II) Elkins, W. Va.
Region III	Thomasville, Ga. 31792	Thomasville, Ga.	(III) Kansas City, Mo.
Region IV	Federal Center Battle Creek, Mich. 49016	Battle Creek, Mich.	(IV) Shreveport, La.
Region V	Federal Center Denton, Texas 76202	Denton, Texas	(V) Oklahoma City, Okla.
Region VI	Denver Federal Center Hdq. Denver, Colo. 80225	Denver, Colo.	(VI) Omaha, Neb.
Region VII	Santa Rosa, Calif. 95403	Santa Rosa, Calif.	(VII) Colorado Springs, Colo.
Region VIII	Bothell, Wash. 98011	Bothell, Wash.	(VIII) Kingman, Ariz.

*The formation of ten Regions is in process. OEP has already moved to established headquarters in the Regional Offices. OCD and EPGA have not as yet changed from those offices indicated in Figure 93.

New Defense Regions, Aug. 30, 71

Region	Address, telephone	States served
Boston (I)	JFK Federal Bldg., Room 2003 L, Boston, Mass. 02203. Telephone: (900) 223-2400 or 4063, Area Code 617.	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont.
New York City (II)	26 Federal Plaza, Room 1355, New York, NY 10007. Telephone: (900) 466-6450, Area Code 212.	New Jersey, New York, Puerto Rico, Virgin Islands.
Philadelphia (III)	Industrial Valley Bank Bldg., Suite 1600, 1700 Market St., Philadelphia, PA 19103. Telephone: (900) 524-2435, Area Code 215.	Delaware, Maryland, Pennsylvania, Virginia, West Virginia, District of Columbia.
Atlanta (IV)	Continental Insurance Bldg., Suites 514, 518, 520, 161 Peachtree St., NE., Atlanta, GA 30303. Telephone: (900) 526-4401 or 4545, Area Code 404.	Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee.
Chicago (V)	33 East Congress Parkway, Room 204 A, Chicago, IL 60604. Telephone: (900) 891-5111, Area Code 312.	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin.
Dallas (VI)	Federal Bldg., 1100 Commerce St., Room 4C-38, Dallas, TX 75202. Telephone: (900) 749-1111, Area Code 214.	Arkansas, Louisiana, Oklahoma, New Mexico, Texas.
Kansas City (VII)	New Federal Office Bldg., 601 East 12th St., Room 142, Kansas City, MO 64106. Telephone: (900) 374-5631, Area Code 816.	Iowa, Kansas, Missouri, Nebraska.
Denver (VIII)	Federal Regional Office Bldg. 710, Denver, CO 80225. Telephone: (900) 837-4981. Rent—837-3981. Price—837-4856. Wage—837-3876. Administration—837-3827. Area Code 303.	Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming.
San Francisco (IX)	450 Golden Gate Ave., Room 2029, San Francisco, CA 94102. Telephone: (900) 556-7746. Wages—556-2452. Prices—556-6260. Rent—556-7027. Area Code 415.	Arizona, California, Hawaii, Nevada, American Samoa, Guam.
Seattle (X)	Federal Office Bldg., Room 1095, 909 1st Ave., Seattle, WA 98104. Telephone: (900) 442-4552, Area Code 206.	Alaska, Idaho, Oregon, Washington.

[FR Doc.71-12886 Filed 8-30-71;2:10 pm]

In peace time, the Office of Emergency Preparedness, OEP (or ODR during a war), the Office of Civil Defense, and the Emergency Petroleum and Gas Administration and other agencies have a full-time but skeleton staff at each center. At a few, the OEP and OGD offices are combined. These employees work daily with local authorities and industry to assist them in emergency planning and civil defense problems and stand ready to go into immediate action in case of a sudden attack. Figure 94 shows the chain of executive function of the Office of Oil and Gas relationship to OCD and OEP activities. The regional organization of EPGA is shown in Figure 95. The peace time functions of the Office of Oil and Gas, Department of the Interior, is shown in Figure 96.

During a war, there will be central resource management, as necessary. The EPGA serves all government agencies as the resource agency for crude and petroleum products and natural gas. It will be the EPGA's job to see to it that industry produces as much crude oil as is needed, refines it into the needed petroleum products, and transports them through its pipelines and other facilities to the military, industries, and to other terminals urgently needing the products. An all-out effort will be made to keep normal routes of supply open and active to serve both domestic and foreign allies' needs. The various duties of the EPGA are defined in Chapter 10 of the National Plan for Emergency Preparedness.[95] In general, EPGA will have a two-way function. (1) It serves as a liaison between the needs of its industry and other supporting executive groups. (2) It serves other groups as a source of supply as needed. These functions will be outlined below.

The above story is told in detail in "What is the Emergency Petroleum and Gas Administration"[99] prepared by the National Petroleum Council. One interested in this phase of emergency preparedness should also consult "Civil Defense and Emergency Planning for the Petroleum and Gas Industries" prepared by the National Petroleum Council.[100]

The Plan in Action

Any concerted attack on the United States will most likely seriously damage a number of our main arteries of petroleum transportation and many localized facilities. It is unlikely that destroyed plants could be rebuilt, but great effort will be made to salvage functional equipment and exchange parts and partially refined products between workable units of nearby plants so as to produce the needed end products as quickly and as effectively as possible.

The National Plan spells out the responsibility of the oil and gas (EPGA) groups as follows:[95]

"Under limited emergency conditions the Federal Government would carry on such programs and invoke such emergency control measures as necessary to assure adequate supplies and the best use of petroleum and gas for national defense and essential civilian purposes.

"The extent to which EPGA would be activated would be determined by the Secretary of the Interior.

"State and local Governments would be called upon to adapt their normal petroleum and gas regulations to fit prevailing emergency conditions, to assist the Federal government in administering a petroleum consumer rationing program if such a program were needed, and to control the distribution of secondary inventories of petroleum products as requested by Interior or EPGA.

"When activated, EPGA would take actions as:

Making continuous studies of petroleum and gas supplies and requirements for the current emergency and possibly more serious circumstances.

Developing programs for and directing the operations of the petroleum and gas industries as necessary to meet essential requirements.

Making recommendations on applications for available financial aids and incentives in connection with programs for increasing the capacity of petroleum and gas facilities.

Submitting requests to appropriate agencies for materials and equipment needed by the petroleum and gas industries, making allotments of the materials and equipment allocated, and within the authority granted by the Federal agency responsible for the allocation of construction materials, issuing authorities for construction projects.

Requesting assistance from appropriate agencies in obtaining or retaining manpower for petroleum and gas programs.

Submitting to the Office of Emergency Transportation (OET) claims for needed rail, highway, inland waterway, lake, and ocean transportation and related port facilities.

Advising OEP (or the Economic Stabilization Agency, if established) on supplies of petroleum products available for distribution through petroleum consumer rationing programs and on adjustments in economic stabilization measures adversely affecting the supply of petroleum or gas needed to meet essential requirements.

Consulting the Department of State, other Federal agencies concerned, and, as appropriate, international organizations and foreign nations on those petroleum and gas problems and programs of mutual interest.

Providing OET* with data on the capacity of pipelines and the movement of petroleum and gas through them."

Actions in General War

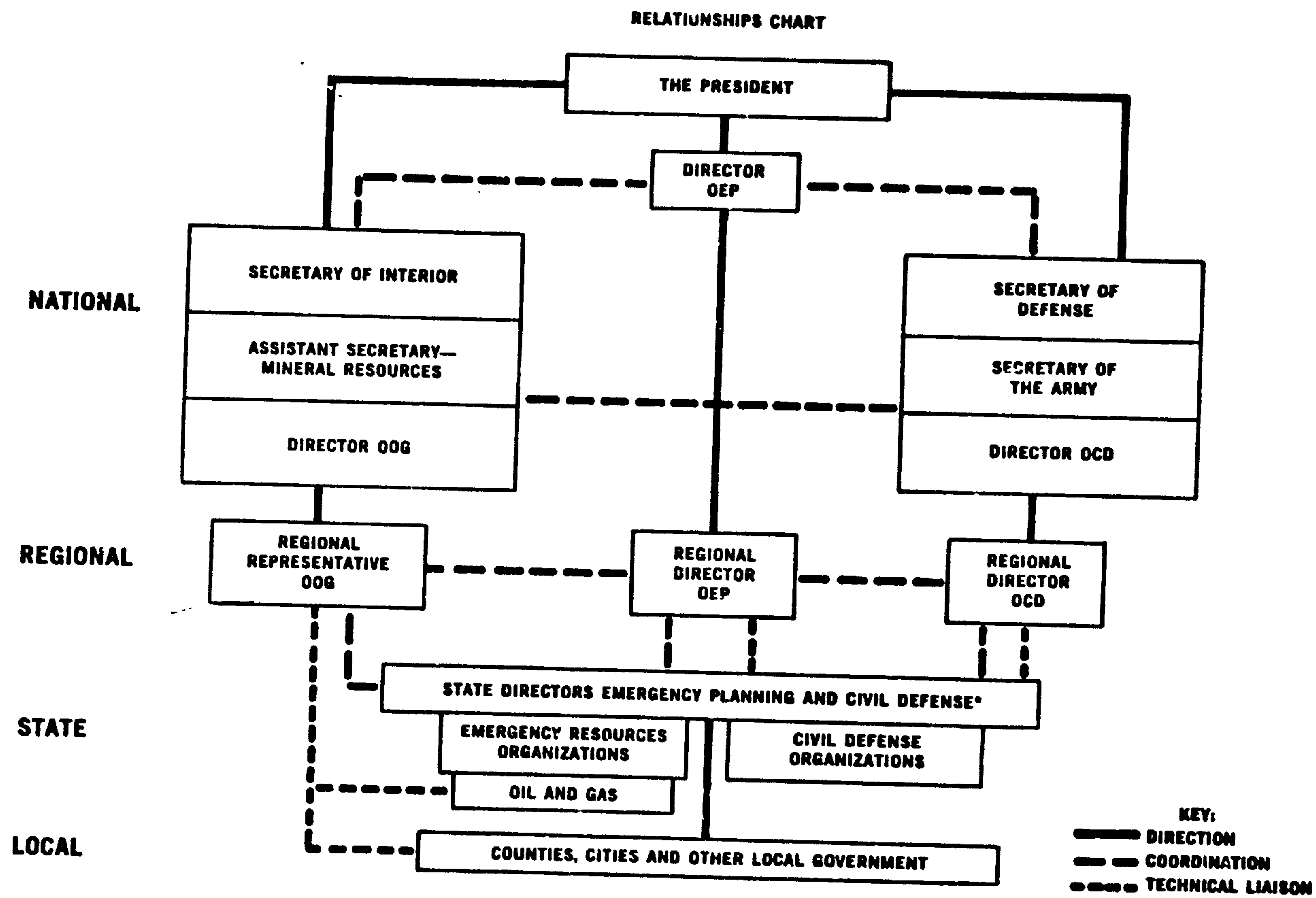
"Under conditions of an attack upon the United States the types of actions listed below would be taken. Actions in the initial postattack period would, to the extent feasible, be in accordance with orders and guidance previously issued by OEP and those issued by EPGA.

"The entire EPGA organization would be automatically activated.

99 National Petroleum Council "What is the Emergency Petroleum and Gas Administration" Department of Interior request- Reprinted by Civil Defense (Free on request)

100 National Petroleum Council "Civil Defense and Emergency Planning for the Petroleum and Natural Gas Industries" Volumes I and II Department of Interior request- Reprinted by OCD March 19, 1964

* Office of Emergency Transportation, a division of the Department of Transportation (DOT)



OEP—OFFICE OF EMERGENCY PLANNING
OOG—OFFICE OF OIL AND GAS
OCD—OFFICE OF CIVIL DEFENSE

* In many states there is one director for both emergency planning and civil defense. In other states there are both a Director of Emergency Planning responsible for management of resources and a Director of Civil Defense responsible for civil defense matters.

Figure 94. Pre-Emergency Planning & Civil Defense[98]

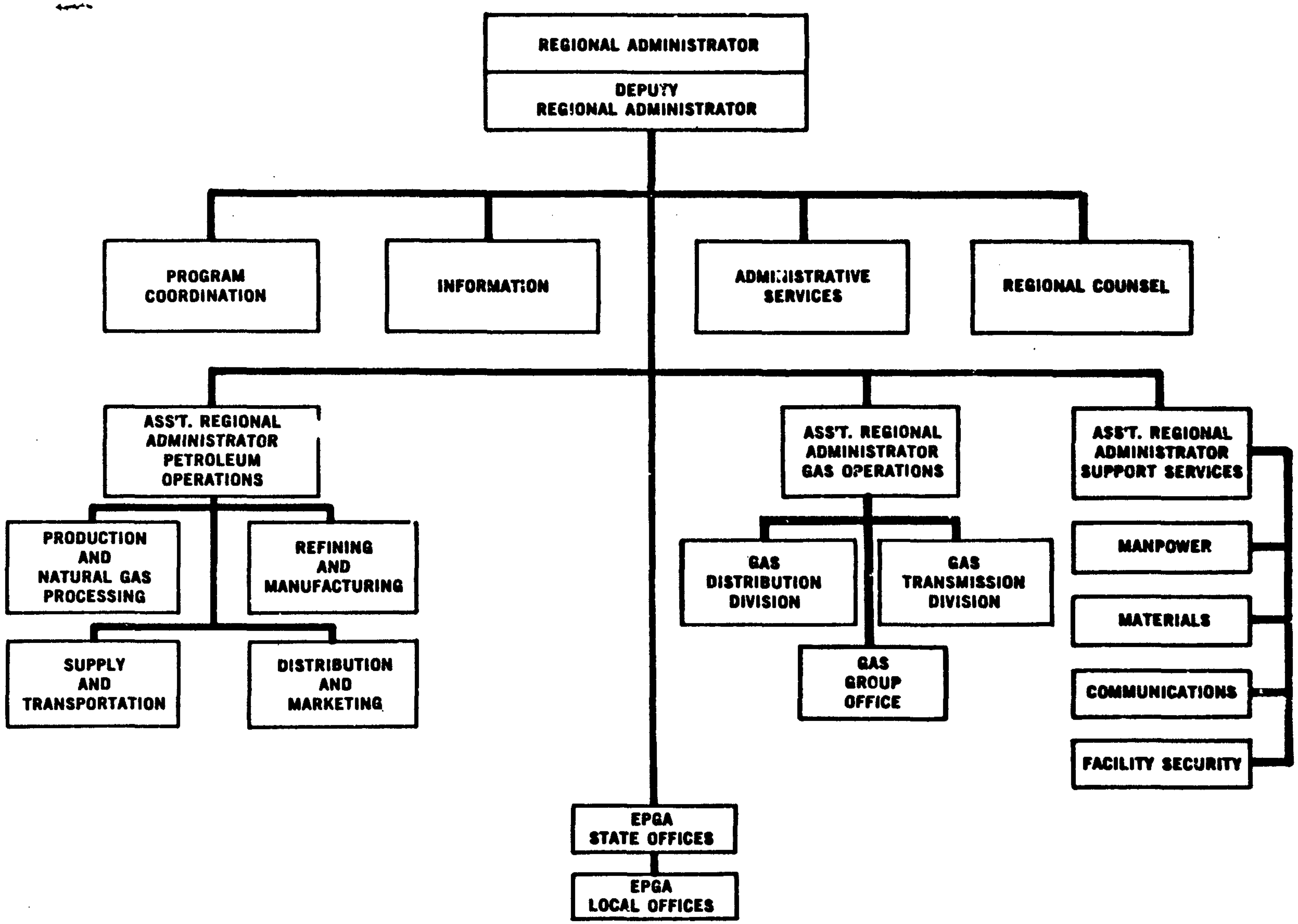


Figure 95. Regional Organization—Emergency Petroleum and Gas Administration[99]

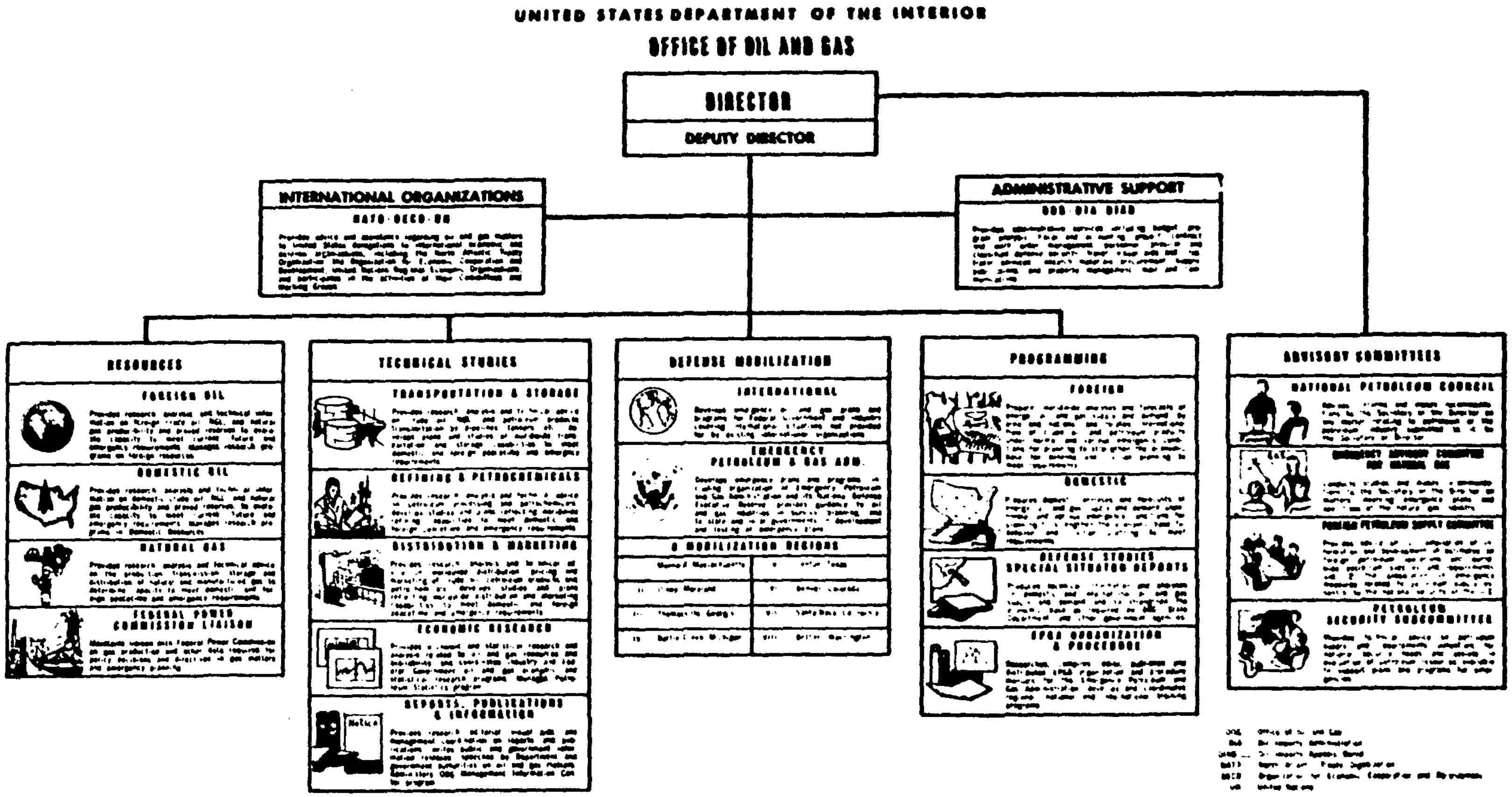

UNITED STATES DEPARTMENT OF THE INTERIOR
OFFICE OF OIL AND GAS
DIRECTOR
DEPUTY DIRECTOR
INTERNATIONAL ORGANIZATIONS
NATO-OECD-UN
ADMINISTRATIVE SUPPORT
RESOURCES
FOREIGN OIL
DOMESTIC OIL
NATURAL GAS
FEDERAL POWER COMMISSION LIAISON
TECHNICAL STUDIES
TRANSPORTATION & STORAGE
REFINING & PETROCHEMICALS
DISTRIBUTION & MARKETING
ECONOMIC RESEARCH
REPORTS, PUBLICATIONS & INFORMATION
DEFENSE MOBILIZATION
INTERNATIONAL
EMERGENCY PETROLEUM & GAS ADM.
8 MOBILIZATION REGIONS
PROGRAMMING
FOREIGN
DOMESTIC
DEFENSE STUDIES SPECIAL SITUATION REPORTS
EPGA ORGANIZATION & PROCEDURE
ADVISORY COMMITTEES
NATIONAL PETROLEUM COUNCIL
FOREIGN PETROLEUM SUPPLY COMMITTEE
PETROLEUM SECURITY SUBCOMMITTEE

Figure 96.

"*Petroleum and Gas Industries.* These industries would:

Maintain operations or resume them as soon as possible.

Establish contact with the appropriate EPGA office.

Within their capabilities, meet essential requirements for petroleum and gas.

Invoke mutual aid arrangements, coordinating actions with State and local governments as appropriate.

Report to EPGA on damage and estimated remaining capabilities versus requirements.

Report to EPGA on needs for manpower, materials, and services required to maintain operation.

"*State and Local Governments.* State governments, with local governments participating in accordance with predetermined arrangements, would cooperate with the Federal Government in carrying out petroleum and gas emergency plans. They would endeavor to insure that supplies of petroleum and gas subject to their control were directed to essential uses.

"They would stop deliveries of petroleum products from secondary inventories, including service stations, except for emergency uses (such as fuel for ambulances, police and fire vehicles, hospitals, and military vehicles and facilities).

"This action would be in support of the Federal Government's general freeze order temporarily prohibiting all retail sales except for essential purposes. It would conserve petroleum stocks until the State and its political subdivisions could institute distribution and rationing controls for which they are responsible.

"Other specific actions would include:

Alleviating initial local shortages by releasing petroleum products from secondary inventories at other locations within the State.

Instituting and carrying on petroleum consumer rationing programs until the Federal rationing agency could absorb and administer them.

Directing, as necessary, the distribution of gas to consumers by all local gas distribution utilities within the State.

Ordering the curtailment of nonessential uses and the conservation of petroleum and gas, should the supply be insufficient for all essential purposes, unless EPGA had issued such an order applicable to a larger area including the State.

Requesting EPGA to provide additional amounts of gas to the State, should a shortage for essential purposes still exist after curtailment and the institution of conservation measures.

Resolving conflicts between essential uses, users, or localities within the State, when secondary petroleum inventories or gas available for distribution within the State were insufficient for essential needs.

Referring to the EPGA regional office for decision petroleum and gas demands conflicting with those of another State. (Referrals would be made through the EPGA State representative.)

Keeping the proper EPGA field office and the appropriate regional offices of other Federal agencies informed of principal commitments of petroleum and gas supplies, shortages and surpluses, and needs for replenishment.

Consulting with EPGA State and regional offices on petroleum and gas supply.

Forwarding damage reports on petroleum and gas facilities to EPGA and other appropriate Federal regional offices.

In the immediate postattack period, facilitating emergency restoration and repair to serve essential needs.

Permitting petroleum and gas companies to retain for their use their wholly owned communication facilities, or those leases for their exclusive use, subject to Federal regulations.

"*EPGA Field Offices.* In accordance with its assigned duties and postattack capabilities, each would:

Direct stoppage of pipeline movements of crude oil and petroleum products and transmission of natural gas to inoperable facilities.

Direct rerouting of crude oil and petroleum products, enroute by water or by overland transportation, from facilities made inoperable by the attack to safe areas where needed; work with transportation agencies to effect such movements.

Assess damage to petroleum, petrochemical, and gas facilities and determine remaining capabilities. Forward this data to the appropriate EPGA and OEP offices.

Direct surviving petroleum, gas, and petrochemical production and processing facilities to meet essential needs.

Provide advice and guidance to State regulatory authorities regarding the production of crude oil and natural gas for essential needs.

Allocate petroleum products from primary inventories to secondary inventories, to military and AEC installations, to ports for exports, and to industrial plants usually supplied by primary inventories; allocate gas from transmission lines and storage to local utilities, to military and AEC installations and industrial plants served directly by transmission lines, and for export.

Submit to the OEP Regional Office for adjudication appeals from allocation decisions.

Advise and assist OEP-OCD Regional Offices and State and local governments on petroleum and gas matters, including plans for replenishment of secondary stocks of petroleum products and for making gas available to local utilities.

Assist, as appropriate, in the transfer of manpower, equipment, and materials among petroleum and gas companies.

Request assistance from appropriate agencies in obtaining communications, transportation, electric power, manpower, materials, equipment, and other resources needed for the petroleum and gas industry.

"*EPGA National Headquarters.* In addition to taking applicable limited-emergency actions, the EPGA national headquarters, with the assistance of field offices as appropriate, would:

Estimate surviving national capabilities of the petroleum, gas, and petrochemical industries, in relation to direct attack effects and radioactive fallout hazards, and the availability of essential supporting resources such as electric power, communications, transportation, supplies, and manpower.

Issue orders and regulations governing the repair and the reconstruction of damaged facilities by the petroleum, gas, and petrochemical industries.

Revise existing orders or issue new orders and directives to control the production, processing, pipeline movement, storage, and use of petroleum and gas.

Issue instructions on the use of requisitioning powers.

In accordance with foreign policy guidance of the Department of State, establish and administer international programs to assure to the United States, its allies, and other Free World nations supplies of petroleum and gas for essential purposes."

Work with Other Groups. The EPGA will receive demands for petroleum from many groups in addition to the military. Further, the EPGA will have claim on other agencies for steel, chemicals, electric motors, and many other products needed by industry to restore their refineries and petroleum systems to operation.

It is probable that one of the most active associations will be with the mobilization agency of the Department of Commerce, the Bureau of Domestic Commerce. This group is responsible for those defense mobilization and emergency preparedness functions that relate to industrial production and distribution. These functions are similar to those of EPGA, but are related to manufacturing and general commerce. Figures 97, 98, and 99 outline their responsibilities that in many respects run parallel to those of the EPGA.[101]

---

101 Department of Commerce "Preparedness in the Chemical and Allied Industries" In cooperation with the Department of Defense, OCD. 1968 Supt. of Documents 45¢

There is an Executive Reserve organization for each of the following areas:

- Department of Agriculture
  - Agricultural Stabilization and Conservation Service
  - Consumer and Marketing Service
- Department of Commerce
  - Bureau of the Census
  - Bureau of International Commerce
  - Bureau of Domestic Commerce
  - Maritime Administration
  - Office of the Secretary
- Department of Defense
  - Department of the Army, Office of Civil Defense
  - Office of the Secretary
- Department of the Interior
  - Office of Minerals and Solid Fuels
  - Office of Oil and Gas
- Department of Labor
- Department of Transportation
  - Bureau of Public Roads
  - Office of Emergency Transportation
- Interstate Commerce Commission
- Office of Emergency Preparedness

BUSINESS AND DEFENSE SERVICES ADMINISTRATION (BDSA), DEPARTMENT OF COMMERCE:

- Provides industry with protection guidance materials adapted to the needs of assigned facilities.
- Promotes a national program to stimulate disaster preparedness and control in order to minimize the effects of overt or covert attack.
- Maintains continuity of production and capacity to serve essential users in an emergency.
- Administers the *Defense Materials System* (DMS), which is a body of government regulations, orders, and procedures designed to:
  - (a) Direct the flow of materials and products to the Nation's "defense programs" by providing a priority for the purchase of materials by contractors, subcontractors, and their suppliers.
  - (b) Permit the maintenance of an administrative means for promptly mobilizing the industrial resources of the country in a limited or general war.
- Offers priorities assistance to restore a defense plant damaged in a presidentially-declared major disaster (e.g. flood, fire, hurricane, etc.) and thereby assists it to resume production.
- Identifies those products and services, and their producing or supporting facilities, which are of exceptional importance to mobilization readiness, national defense, or postattack survival and recovery.
- Conducts general supply-requirements studies and component studies to determine the capability of industry to meet industrial production requirements under various emergency conditions.
- Develops methods for the assessment of industrial production capability in the event of enemy attack, and the dependency upon suppliers of materials, components, and services.
- Conducts training and recruitment programs for its complement of the National Defense Executive Reserve* in order to provide a capability at national and field levels to carry out Federal responsibilities with respect to the management of emergency industrial production and distribution.
- Maintains, at national relocation sites and selected regional sites, essential working data required for emergency operations (see page 41, "OEP-OCD and Department of Commerce Regions").

STATE AND LOCAL GOVERNMENTS:

Continually develop emergency plans for:

- Estimating inventories under Federal guidelines.
- Assessing production capabilities.
- Determining emergency requirements.
- Distributing essential items within each State.
- Establishing a "State Emergency Production and Distribution Agency" to perform the above activities, when needed.

INDUSTRY:

- Cooperates with the Federal Government in developing preparedness plans.
- Accepts and performs contracts on a priority basis for defense, atomic energy, space, and other national security programs, in compliance with the Defense Production Act and the Defense Materials System.

---

* The *National Defense Executive Reserve Program*, in which the Business and Defense Services Administration has a major part, is a mobilization readiness program for recruiting and training business executives for emergency mobilization assignments. The Program was established under the authority of the Defense Production Act of 1950 as amended. Its purpose is to recruit and train executives and professional persons to serve the Government in key civilian positions at local, regional, or national headquarters during periods of national emergency.

Figure 97. Production and Distribution Responsibilities (Peacetime)[101]

(Includes a limited war condition where a limited national emergency has *not* been officially proclaimed)

Business and Defense Services Administration (BDSA), Department of Commerce:

- Issues a finding, with approval of OEP, under Sec. 101(b) of the Defense Production Act to permit use of priorities in support of essential civilian production, construction, and distribution programs.
- Brings headquarters and field organizations to the strength required to meet the emergency through the partial activation of the BDSA complement of the National Defense Executive Reserve and through full utilization of field office staffs.
- Initiates programs for expanding the capacity of production facilities or for increasing the output of existing facilities.
- Activates the BDSA emergency relocation sites in preparation for carrying out production and distribution responsibilities.

State and Local Governments:

- Support national resource mobilization policies and goals.
- Comply with Federal rules and regulations on resource production, distribution, and use.
- Activate, to the extent necessary, planned emergency production and distribution measures consistent with national policies and programs.

Industry:

- Fulfills defense, atomic energy, space, and essential civilian programs in cooperation with the Federal Government.
- Complies with Federal regulations relating to industrial production, construction, and the use of industrial resources.
- Distributes certain materials and products in compliance with Federal regulations.

Figure 98. Production and Distribution Responsibilities (Limited War)[101]

(Where a limited national emergency has been officially declared)

Business and Defense Services Administration (BDSA), Department of Commerce:

- Provides automatic purchase priorities for the use of companies and persons producing essential items and furnishing essential services in obtaining from nonretail sources: maintenance, repair, and operating supplies; capital equipment; and production materials.
- Limits the distribution of inventories of selected finished essential items to the filling of priority orders or by specific authorization of appropriate Federal and State authority to avoid the dissipation of existing supplies.
- Assumes control and supervision of the 42 field offices of the Department of Commerce.
- Activates the entire BDSA Executive Reserve. Provides emergency priorities assistance to Federal, State, and local government agencies, and to industry in expediting industrial production and directing distribution to meet essential needs.
- Issues regulations, as needed, to support restoration and rehabilitation programs.
- Implements industrial production and distribution programs for essential resources for recovery of the country.
- Initiates procedures for the rehabilitation of facilities after attack.

State and Local Governments:

- Assist the Federal Government in its industrial resources management responsibilities, if Federal control were inoperable and until it was reestablished.
- Conduct their own State programs for the management and distribution of locally available survival supplies.
- Activate "State Emergency Production and Distribution Organizations" to:
  - a. Support "State Civil Defense and Rationing Authorities".
  - b. Assist producers of essential items or services in locating sources of supply.
  - c. Furnish data relating to remaining supplies of and requirements for essential items within the States.

Industry:

- Cooperates with appropriate government authorities in operating its facilities in accordance with the guidelines set forth by the Federal Government for the survival, restoration, and rehabilitation of the Nation.
- Provides essential goods and services at levels needed to support national objectives.
- Curtails the operation of plants and facilities engaged in nonessential activities and, to the extent practical, converts them to essential uses.
- Complies with government rules and regulations relating to production, distribution, acquisition, and use of resources.
- In a "cut-off" situation where Federal guidance is temporarily unavailable, accepts direction from the States and their political subdivisions until effective Federal direction and control are reestablished.

Figure 99. Production and Distribution Responsibilities (General War)

(Where a national emergency or state of war has been officially declared or is evident by an attack)

Summary

Figure 100 illustrates the teamwork between Civil Defense, (Figure 100) military and industry toward the goal of total readiness. The various degrees of international tension are shown and examples of the response made to the conditions by the Office of Oil and Gas in the past and the planned response for future contingencies.

the plant, the stock piling of items likely to be hard to get and other items peculiar to an individual plant.

Most local plans are likely to assume that corporate management will be unchanged. It is not probable, in cases of nuclear war, that all top management will be spared. Therefore, expert planners provide for the continuity of corporate management in case of nuclear war. Such legal provisions, to insure that the management of our petroleum and natural

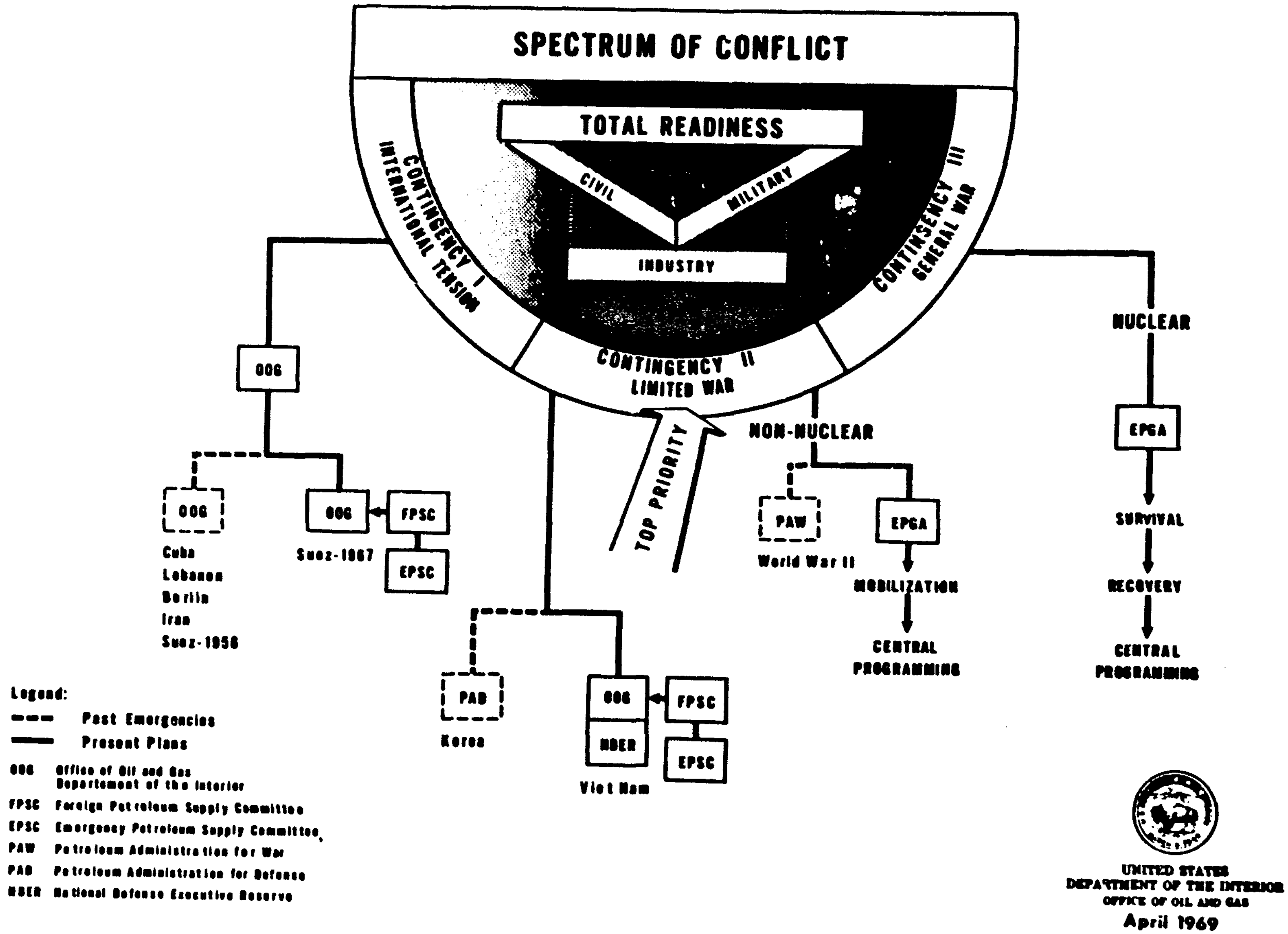


Figure 100. Anticipated EPGA Involvement in Emergency Situations

gas resources are consistent with military and economic requirements, but they also will "provide flexible guidance so that surviving manpower and resources can be effectively utilized immediately and mobilized to the point where centralized programming can be achieved to best use the nation's resources."[98]

It is important that each oil and gas producing company, the natural gasoline companies, the petrbleum refining and all closely related industry ally themselves with the Civil Defense and EPGA program; and further, develop emergency plans within their individual plants.

Plant Operation with Reduced Personnel

Plans- Each plant needs an emergency plan, not only for wartime situations, but also as a matter of preparedness for natural disasters, explosions, or other man-created damage. Much has already been said regarding these potential disasters. A company plan should cover all phases of the operation including management continuity, emergency assignment of employees, emergency communications, self-contained fire fighting and security force, emergency employment problems, special protection for workers remaining in the plant, the stock piling of items likely to be hard to get and other items peculiar to an individual plant.

Most local plans are likely to assume that corporate management will be unchanged. It is not probable, in cases of nuclear war, that all top management will be spared. Therefore, expert planners provide for the continuity of corporate management in case of nuclear war. Such legal provisions, plus the preservation of blueprints, operation records, accounts, and other company records, stand out as items often overlooked in emergency planning. A chain of authority needs to be established so that heirs to plant management, isolated by a disruption of communication from parent groups, can make the necessary policy decisions and have the emergency powers that will permit continuity of operation. Figure 101 is a partial check list. A special study was made of this subject by the American Society of Corporate Secretaries, Inc.[102]

Specific measures for the assurance of effective postattack business, industrial leadership, and operating direction are:

(1) Those necessary to assure a functioning board of directors.

(2) Those relating to establishment of lines or succession for key officers and operating personnel.

(3) Those relating to establishment of an alternate company headquarters.

(4) Those relating to the records preservation.

The Board of Directors- The American Society of Corporate Secretaries, Inc. polled the opinion of over 300 corporations as to legal requirements involving the emergency functions of a corporate Board of Direction. Because of the importance of this information, it is reprinted here. A summary of their opinion is as follows:

"The underlying principles of *continuity of management* are consistent with long established legal concepts governing the corporation's normal capacity for 'succession'. That is it continues in existence until terminated by constitutional or statutory provisions, dissolution, or until the expiration of the corporate charter.

"The laws in many States indicate that a corporation shall have succession for the period of years defined in its charter and if no period is stated, then in perpetuity.

"The key measure to be taken to provide *continuity of management* is assurance that the board of directors can operate even though a large number of members of the board are dead, injured, or are unavailable for board meetings.

"The board of directors represents the corporate body and its members are the executive representatives of the corporation. It is through it that all ordinary business of the corporation, within the scope of its corporate powers, is carried on, and it can do what is necessary to be done unless specifically restricted by the articles of incorporation or the bylaws. Restrictions are unusual. Normally the board has full power to regulate and conduct the business of a corporation according to its best judgment."

Amendment of Corporate Bylaws and Regulations

Bylaws of corporations need to provide for very flexible powers of the survivors of a nuclear attack.

The discussion cited above continues to point out provisions required to meet emergency conditions.

1. Provide for the reduction of the quorum number of the board and for the authority to be given to survivors to fill board vacancies.
2. Provide for an emergency management and for a succession of officers.
3. Provide for emergency alternate directors.
4. Provide for emergency legislation.
5. Provide for a succession of executive officers by preparing succession lists.
6. Provide for an alternate headquarters.
7. Provide for the preservation of records, and designate those records considered vital. Also arrange for access to the records by authorized persons.
8. Provide for instructions to officers and to key employees as to where to find and how to use company's vital records.
9. Provide for emergency financing to meet payrolls, restoration of damaged plants, and to purchase materials.
10. Provide for postattack training of substitute or provisional employees.
11. Provide instruction to key personnel so as to acquaint them with all emergency provisions.
12. Provide emergency security measures to protect personnel and the equipment to the industry.
13. Provide emergency communications ability.
14. Provide emergency protection of key employees remaining to restore the plant to full operation.

The manual quoted above continues with several examples of policy statements, suggested letters and forms to use in the event of a national disaster.

Executive Succession- Each company will have ideas to meet this problem. A discussion of this situation is as follows:

102 American Society of Corporate Secretaries, Inc. "Continuity of Corporate Management in Event of Nuclear Attack" 1963 Office of Civil Defense, Revised Dec. 1970

1. Has the probability of damage and difficulty of procuring repair replacements been analyzed?
2. Are secondary water supplies and emergency electric power available at critical company facilities?
3. Have building and equipment designs, specifications, flow charts, and layout been simplified so as to reduce emergency repair problems?
4. Has standard equipment been substituted whenever possible for special or long lead-time items?
5. Does the company have a complete set of building plans that could be used for an immediate start on emergency repairs?
6. Have "fail-safe" provisions (instrumentation or other devices to assure safe shutdown) been incorporated into plant facilities?
7. Have engineering and production practices been reviewed with a view toward facilitating rapid shutdown or reducing damage in the event of forced shutdown?
8. Does each facility have an adequate supply of spare parts and materials for maintenance, repairs, and operations if supplies are shut off by an attack?
9. Have copies of designs, process flow charts, specifications, maps of plant utilities, etc., been stored at safe locations?
10. Has color coding or other identification been applied to all tanks, process vessels, pipelines, pumps, steam lines, fire lines, etc., which require emergency repair after an attack or other disaster?
11. Does continuity or early resumption of operations after attack require:
    - (a) Structural strengthening of buildings?
    - (b) Installation of damage-resistant materials?
    - (c) Special shelters for emergency operating personnel and equipment?
    - (d) Protection for plant production services and utilities?
12. How much blast pressure can the company facilities withstand?
13. Has the number of potential ignition points at company facilities been minimized?
14. What is the fire resistance of company buildings?
15. What is the combustibility rating of the facility's contents?
16. Do the manufacturing processes, materials, or by-products create toxic hazards?
17. Can hazardous areas be quickly evacuated?
18. Does each company facility afford adequate fallout shelter for the employees at that location?
19. Is the physical arrangement of space, equipment, passageways and exits suitable for the mass movement of employees to shelters?
20. Have employees been trained and equipped for emergency operations, including radiological monitoring, shelter management, and medical self-help?

Figure 101. Managerial Factors in Emergency Planning[101]

"When disaster strikes, 100 executives and other key personnel may be killed or injured. Consequently, corporate emergency planning should anticipate and provide for such contingencies. They may be accomplished by developing appropriate succession lists supplemented by job descriptions and 'delegation of authority letters' for the successors. One large corporation defines this requirement as follows in its emergency planning manual:

A succession list of one or more names should be prepared for the top position in each unit. Succession lists for positions below the top are not recommended as it is usually better for the new manager to make appointments. However, unit subdivisions, which are remote from unit headquarters, ought to have succession lists for their top positions since communications may be interrupted . . . .

"The procedures for compiling such lists and the related emergency authorizations naturally vary with different companies. For example, the Corporate Emergency Plan of one multi-company organization states in part:

Succession lists may be made by job title or by name, but in either case, dispersal of those on the lists is of great importance to improve the possibility of having a surviving member.

Each individual on the list should be so informed and given a Delegation of Authority letter as follows:
In any emergency in which (the) corporate office in New York is incapacitated, causing absence of instructions from higher Company authority, and until such instructions from New York or an alternate corporate office are received, you are authorized to do the following:

1. Continue your general administration of and be responsible for assets, whether useable or unuseable, and all activities necessary to the proper conduct of the business, which are now within your jurisdiction, in cooperation with and as permitted by Government authorities.

2. Hire, assign duties and work schedules, train, pay, release or reassign and otherwise direct the activities of manpower that is now or may come within your jurisdiction, in connection with and as permitted by Government authorities.

3. Combine, pool, and otherwise join in mutual aid arrangements with other unit managers and with industry with respect to raw and finished supplies, materials, equipment, facilities, security, manpower and money.

4. Dismantle, remove, salvage, repair, reconstruct or otherwise rehabilitate damaged equipment and facilities deemed essential and vital by Government authorities.

5. Delegate to an approved list of senior supervisory employees this authority to act for you in your absence."

Company Emergency Plans

Most plants have some provisions for emergency operation. (See Figure 101.) One plant has assumed that the people most likely to stay with the plant in case of a nuclear blast are those without strong family ties. A list of names and assignment of an emergency staff is updated every six months. Persons so listed have pledged themselves to emergency service and are trained for the occasion. The trend toward automatic operation requires a more highly trained than usual operator. Men selected to serve on the emergency staff are educated, stable, straight thinking, and extremely loyal employees.

Several publications outline suggestions for emergency preparation. Civil Defense and Emergency Planning for the Petroleum and Gas Industries[100] contains emergency plans designed specifically for the petroleum industry. A plan for emergency operation not only is needed, but various phases of management will need specific instruction manuals so that each department or increment of the operation knows what to do in a disaster. A number of helpful publications exist. One in general use is entitled "A Guide to Developing a Company Civil Defense Manual".[103] Detailed check lists and defense procedures are given. The Industrial Civil Defense Workbook[104] is a helpful guide designed for use of small industries. A check list for widespread company planning is given in Table 48.[105]

This outline was also adapted and expanded for use in preparation for sabotage, riots, civil disorders, and similar plant emergencies by the Provost Marshal General of the Department of the Army.[106] Preparation of a plant to meet a nuclear attack is insurance serving the company well in time of natural occurrences and internal disorders.

Plans in Service- Most companies now have survival plans, but there are still those too new or those who have not considered their vulnerability that have yet to devise a satisfactory emergency procedure.

A number of active plans have been published by the Office of Civil Defense. These can be adapted as a pattern for related industry. A few company plans available in print are as follows:

Hughes Aircraft Company
General Motors
Standard Oil of New Jersey
Socony Mobil Oil Company
Industrial National Bank of Rhode Island
Western Electric

Some other papers of interest are as follows:

"Preserving the Corporate Structure" N. E. Miller- Pacific Telephone and Telegraph Company, San Francisco, California.

"Industrial and Community Survival" Maxwell S. McKnight- Former Senior Security Officer Socony Mobil Oil Company.

"Disaster Control Planning" Major Donald C. Becker- Chief Industrial Defense Committee, U. S. Army Military Police School, Fort Gordon, Georgia.

"Survival Plans Your Company Can Use" Virgil Couch, Assistant Director Office of Civil Defense, Industrial Participation- Nation's Business.

Civil Defense and Taxes

In matters of corporate taxes, it is well to confer with experts on the subject, for Congress, the Department of Internal Revenue, and the Tax Court make revisions in the rules and their interpretations of the law from time to time.

There are items of tax benefit related to construction and operation for Civil Defense building and program participation. Prentice-Hall, Inc.[107] discusses this subject.

General Observations Section II

Plants operating during and after a nuclear explosion will have not only blast damage problems, but also radioactive fallout and fires. The protection of workers is foremost, but if a retaliatory ability is to be preserved, our industries must be able to make rapid substitutions of equipment and processes, and repairs and rerouting of products where broken lines exist. Plans to handle each plant under emergency conditions and with reduced personnel is essential.

A plan of self help is important for police and public fire fighting equipment will either be blocked from free movement by debris in the streets or will be so busy preventing the development of mass fires that each industry can expect little help if any.

It is estimated that from one-quarter to one-half of over 3,106 counties of the country will be free of weapon effects. These must have plans to help those areas that are having troubles as well as to have plans for their own help should they be less fortunate.

Industry in the areas affected by fallout, fires, and blast damage will need to assist each other so as to maintain maximum industrial output of those plants essential to survival.

Uncontrollable fires in urban areas could involve those plants located in highly populated areas.

Utility services could be cut off so that a self-sustained electric power, water, and fuel supply could suddenly be required. Special plans for emergency management and financing, on-the-job training of substitute personnel, and security made now will be put into automatic action.

Figure 102 shows nine basic concepts under which industry might have to operate during and after an attack. These are as follows:

1. Negative radiation- negative fire
2. Low radiation- negative fire
3. High radiation- negative fire
4. Negative radiation- low fire
5. Low radiation- low fire
6. High radiation- low fire
7. Negative radiation- high fire
8. Low radiation- high fire
9. High radiation- high fire

A well prepared plant should be able to cope with the worst situation of high radiation and high fire. *Few are presently able to do so.*

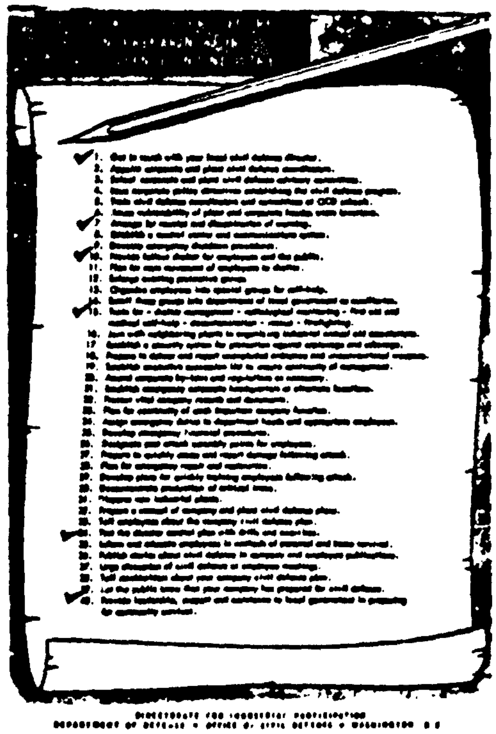
103 Department of Defense "A Guide to Developing a Company Industrial Civil Defense Manual" Office of Civil Defense FG-F-3.8 April 1969 (See local civil defense director)

104 Department of Defense "Industrial Civil Defense Workbook" Office of Civil Defense FG-F 3.3 1966 (See local civil defense director).

105 Office of Secretary of Defense "Industrial Emergency Plan Outline" Defense Industry Bulletin, page 21, July 1968

106 National Association of Manufacturers "A Check List for Plant Security" Cooperative publication with the Department of the Army, May 1968

107 Prentice-Hall, Inc. "How to Protect Your Business in a Nuclear Attack" Special Report, Sect. 4, October 14, 1961



	NEGLIGIBLE FIRE	CONTROLLABLE FIRE	UNCONTROLLABLE FIRE
NEGLIGIBLE FALLOUT	1 NEGRAD NEGFIRE	4 NEGRAD LOFIRE	7 NEGRAD HIFIRE
MODERATE FALLOUT	2 LORAD NEGFIRE	5 LORAD LOFIRE	8 LORAD HIFIRE
SEVERE FALLOUT	3 HIRAD NEGFIRE	6 HIRAD LOFIRE	9 HIRAD HIFIRE

Figure 102. Nine Basic Operating Situations[107]

107 Department of Defense - Federal Civil Defense Guide - Part 6, Chapt. 1 app. 1 - Office of Civil Defense - November 1967.

Table 48. Industrial Emergency Plan Outline[106]

Purpose

( ) Assure orderly and efficient transition from normal to emergency operations.
( ) Delegate emergency authority.
( ) Assign emergency responsibilities.
( ) Indicate authority by company executives for actions contained in plan.

Execution Instructions

( ) Appoint individual(s) to execute plan.
( ) Specify conditions under which plan may be partially executed.
( ) Specify conditions under which plan may be fully executed.
( ) Coordinate plan among all responsible individuals to assure sequence of execution.

Command and Control Center

The command and control center is the plant command post, the focal point for directing all emergency actions. For decentralized operations, all emergency actions should be coordinated through the central control center.
( ) Is location well protected?
( ) Can access be controlled with minimum manpower?
( ) Select alternate location.
( ) Prepare management succession list of executive and administrative personnel and key employees. Designate alternates.
( ) Assure that management continuity and emergency organization are in accord with state corporate laws and company charter or bylaws.
( ) Pre-publish company orders constituting emergency authority.

Planning Coordination (Mutual Aid)

( ) Coordinate plan with local and state officials.
( ) With police departments.
( ) With fire departments.
( ) With adjacent plants and business firms.
( ) With local utilities: power, telephone, transportation.
( ) With employee union officials.
( ) With local news media.

Communications

( ) Adequately cover plant area.
( ) Back-up primary system with two-way radios, walkie-talkies, field telephones, or megaphones (bull horns).
( ) Monitor local and state police radios.
( ) Monitor fire department radios.
( ) Monitor hospital and ambulance radios.
( ) Establish communications with adjacent plants and businesses.
( ) Establish communications with management and key employees.
( ) Train switchboard operators in emergency procedures.
( ) Establish emergency communications procedures.

Personnel

Emergency Notification

( ) Keep switchboards open and operators available.
( ) Designate male operators as alternates for females who may not report.
( ) Establish cascade system of notification for recall to work.
( ) Prepare reporting instructions.
( ) Designate reporting points, primaries and alternates out of emergency areas.
( ) Inform employees of locations and procedures.
( ) Instruct employees to report to points if normal routes to plant are closed.
( ) Plan transportation, *i.e.*, busses, trucks, company-owned or contracted.
( ) Coordinate mutual needs with other plants.
( ) Arrange police escort for emergency repair crews.
( ) Pre-select routes from reporting points to plant.
( ) Plan for escort of female personnel; consider car pools.

Training

( ) Survey secondary skills. Match with emergency requirements.
( ) Train personnel in emergency skills required, where necessary.
( ) Primary or secondary emergency skills. (Relate to survey of secondary skills.)
( ) Train for immediate internal or external emergency repairs.

Situation Briefings

( ) Brief employees on potential for civil disorder. Police can help.
( ) Brief on emergency plans. (Do this with caution. Do not create a scare program.)
( ) During disorder, brief employees daily on impact of riot on plant and community. Must be factual to dispel rumor and speculation.
( ) Prepare employees psychologically to remain on job: need for loyalty, self-restraint; act only as directed by management or police; report rumors to supervisors.
( ) Plan post-emergency recognition of exemplary performance.
( ) Explain impact of emergency on plant.

Evacuation

( ) Designate routes to evacuate buildings or plants.
( ) Inform employees of routes and procedures.
( ) Evacuate by departments (if practical).
( ) Designate primary and alternate exits away from emergency area.

Table 48. Industrial Emergency Plan Outline[105] (Continued)

Electric Power

( ) Coordinate plan with local power companies: transmission lines, transformer banks, alternate distribution lines.
( ) Provide emergency power for lighting and other essentials (not for full production).
( ) Generators, size, location, fuel, operators.
( ) Battery-powered e ipment, flashlights, lanterns, radios, batteries.

Plant Security

Organizational Plans

( ) Develop plant security organization.
( ) Write security plans and procedures.
( ) Report promptly to FBI any actual or suspected acts of sabotage or espionage.
( ) Coordinate with local and state law enforcement agencies.
( ) Have supervisory personnel attend plant protection training.

Guard Force

( ) Organize guard force.
( ) Prescribe qualification standards.
( ) Train guards.
( ) Uniform guards.
( ) Arm guards (check with local officials the authority and legal liability during civil disturbance).
( ) Deputize guards, if necessary. (Check with local officials.)
( ) Assure guard force is on duty at all times.
( ) Issue written orders to guard force.
( ) Set up internal communications for exclusive guard force use.
( ) Plan auxiliary guard force for emergency: company employees, contract guards.

Perimeter Barriers

( ) Inspect security fence (or other barrier) regularly for proper maintenance.
( ) Park vehicles outside of security fence or wall (to reduce fire potential and minimize hazard of concealed explosive or incendiary devices).
( ) Light critical areas.
( ) Install intrusion detection devices.
( ) Post trespass warnings on all barriers.
( ) Use screening to protect lighting fixtures against rocks and other objects.
( ) Insure continuous lighting in parking lots and on ground floors.

Control of Entry

( ) Develop procedures for positive identification and control of employees.
( ) Give samples of identification media (photograph identification cards or badges) to local police. (Essential for crossing police lines or during curfew.)
( ) Guard force controls admittance to facility.
( ) Control movement and parking of vehicles.

Protecting Critical Areas

( ) Identify critical areas within plant.
( ) Enclose critical areas with physical barriers.
( ) Designate specific personnel who may have access to critical areas.
( ) Control admittance to critical areas.
( ) Protect unattended critical areas by locks or intrusion detection devices. (Rotate locks upon notification of impending emergency.)
( ) Develop a key control system.
( ) Develop package and material control procedures.
( ) Protect gasoline pumps and other dispensers of flammables. (Disconnect power source to electrically operated pumps.)

Arms Control

( ) Keep arms rooms locked and under 24-hour surveillance.
( ) Store ammunition in a separate locked location under 24-hour surveillance.

Personnel Security

( ) Conduct pre-employment investigations of applicants.
( ) Check personnel who are authorized access to critical areas.
( ) Brief employees on importance of plant security and vigilance.

Fire Prevention

( ) Post and enforce fire prevention regulations.
( ) Post signs showing location of fire hose connections.
( ) Insure that fire hose connections are compatible with local fire department equipment.
( ) Extend fire alarm system to all areas of facilities.
( ) Determine when fire department can arrive under conditions other than civil disorder: five minutes after report of fire? ten minutes?
( ) Provide secondary water supply for fire protection.
( ) Install fire protection equipment on-site. Maintain properly.
( ) Install mesh wire or screening material to protect roofs of buildings immediately adjacent to the perimeter from fire bombs, molotov cocktails, or other incendiary devices, if feasible. (Check with local fire department.)
( ) Organize employees into fire fighting brigades and rescue squads.
( ) Store combustible materials in well protected areas.
( ) Instruct employees in the use of fire extinguishers.
( ) Conduct fire drills periodically.

Table 48. Industrial Emergency Plan Outline[105] (Continued)

( ) Maintain good housekeeping standards.
( ) Implement recommendations in latest fire insurance inspection report.

Protect Vital Records

( ) Classify and protect vital corporate records, cash and other valuable items.

Property and Liability Insurance

( ) Review property and liability insurance against loss or obligation resulting from riots or other destructive acts.

Emergency Supplies

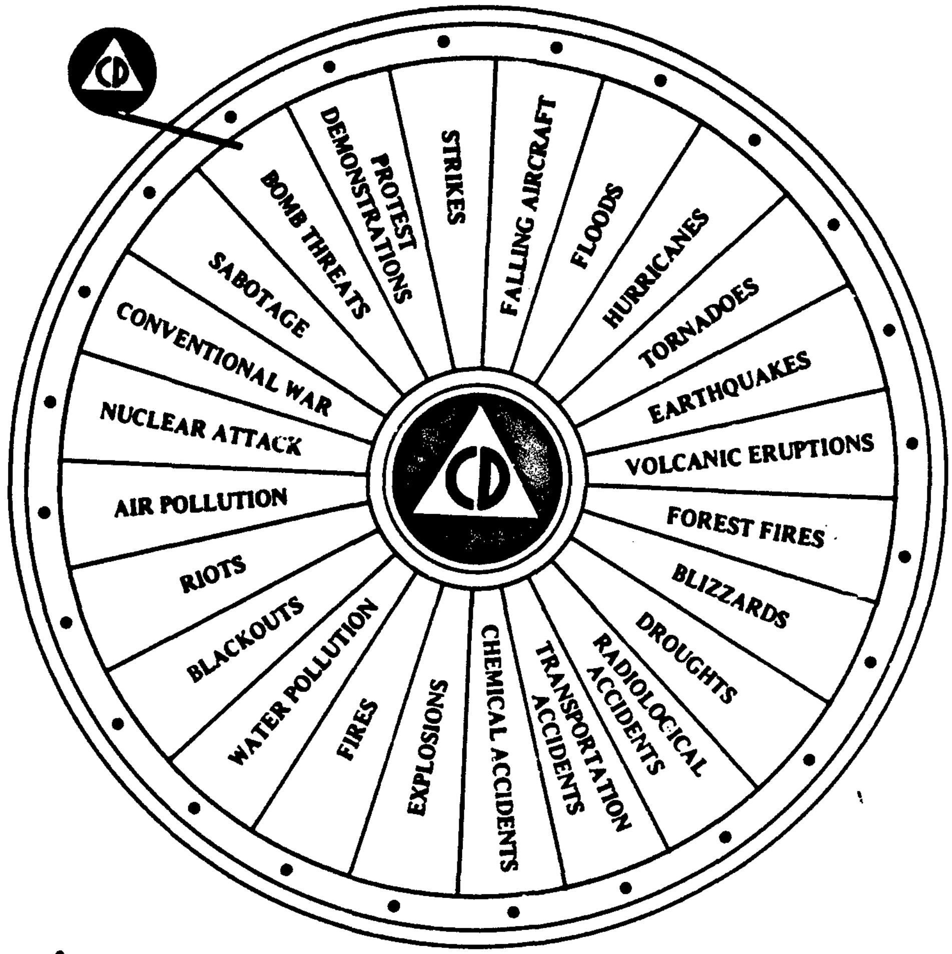
( ) Estimate duration of emergency.
( ) Pre-stock food, water, and medical supplies because conditions may not permit procurement during emergency.
( ) Designate separate sleeping quarters for male and female employees.
( ) Provide sanitation facilities.
( ) Stock administrative supplies.
( ) Stock emergency repair tools, equipment and parts.
( ) Develop procedures for employees to purchase gasoline for automobiles from plant supply in case local stations are closed.
( ) Maintain sufficient inventory of empty 55-gallon drums to be filled with water or sand for use as barricades at entrances.
( ) Have on hand enough barbed wire to form a barrier directly in front of each row of 55-gallon drums. Concertina type wire is very effective.
( ) Maintain supply of panels or screen mesh to protect windows on ground floors.

Test the Plan

( ) Test individual parts of the plan.
( ) Test the entire plan.
( ) Test without prior announcement.
( ) Note weaknesses. Revise plan to include corrective actions.

Preceding page blank

EMERGENCY ROULETTE



Is your company ready for all emergencies ?

Chapter XI

RESTORATION OF OPERATIONS

Introduction

In Chapter VIII, we discussed the results of a possible attack on the country. The scenario given postulated a surviving population of 125,000,000 to 145,000,000 people. In discussing the viability of the United States after a theoretical attack in 1975, Addington,[108] of the U. S. Army Engineers, points out that the combination of labor and industry that created a $900 billion Gross National Product (GNP) would possibly be reduced to the level of 1939. In 1939, a population of 130 million people produced a Gross National Product of $500 billion. By redirecting labor forces and by the utilization of industry for maximum recovery effort, the United States could achieve a GNP equivalent to that of 1961. "In essence, we would have a capability considerably exceeding that with which we came out of World War II." He points out that Germany under Hitler had a population of 78 million people in 1939. Their Gross National Product was $58 billion. Even "with these relatively meager resources, Hitler prosecuted a pretty effective war for 4 or 5 years."

"In summary, a massive nuclear attack on the United States would certainly constitute a catastrophe of the highest order. But although much would be lost, much would remain. Our studies indicate that we would have the capability and, given the will, we can emerge from such a holocaust to maintain a dominant position in the world and sustain the western values we cherish." To do this, however, requires pre-planning, adequately protective building, and widespread training on the part of industry and labor.

Damage Assessment

After an nuclear blast, certainly the first item in the minds of management would be "How much are we damaged?" To be sure, damage assessment will take place continuously during a confrontation, but the likelihood of the attack being "on and over" almost at the same time, leaves little time for "during attack" damage assessment. The explosion damage to installations shown in Section I could have been taken in some wartorn area for the net results are similar. It is even probable that in wartime, refinery management will have more warning, however short it might be, than usually given on the occurrence of a plant disaster.

During an enemy action, it would be ideal for personnel to be in underground bunkers as was the case in Germany, each connected with communication facilities and each with periscopes suitable for direct observation. Obviously, no one will be walking around looking things over, for exposure to radioactive fallout will make this prohibitive. It is in such a situation where automatic equipment would be an asset as would remotely controlled fire fighting capabilities.

It could be possible in areas outside of the immediate vicinity of target areas to have from 15 minutes to several hours in which to take emergency action.

The refinery management in and near target areas can expect to find severe structural damage, uncontrollable fires, fallout problems and a loss of power and utilities. The problem is to assess your damage and, if possible, report your situation to Civil Defense authorities. Certainly the fires and an out-of-control refinery have to be coped with first. Just who can become exposed to radioactive fallout and for how long a time will depend on your local rate of fallout. Radiological monitors will attempt to keep people informed of the atmosphere conditions by radio. It is vitally important that personnel do not leave fallout shelters until radiation is at low, tolerable rates, and then exposure can be only for short intervals. The first to leave will be the decontamination team. Special clothing and equipment is required, and, of course, considerable pretraining; otherwise untrained persons attempting to do such work are most certain to become casualties.

In general, refinery management can find itself in one of several situations after a disaster.

1. Completely damaged- repair impossible
2. Severely damaged- complete repair difficult
3. Damaged- repair possible
4. Not damaged- high radioactive fallout
5. Not damaged- low radioactive fallout
6. Not damaged- no fallout

Radioactive Fallout

Assuming that a refinery is not able to operate automatically for an extended period of time, and has little or no fallout protection in case of an attack warning, all efforts would be made to shut down the operation prior to the arrival of radioactive fallout. Shutdown time by necessity must be very short, but done in such a way as to avoid panic and the certain self-destruction of the refinery if it were totally abandoned. Each operator of a system knows emergency procedures and the end effect of improper shutdown.

Once fallout has precipitated on a refinery, decontamination is necessary prior to any startup of operations.

By use of general information from almost 300 petroleum refineries and detailed information from 16 refineries, estimates were made as to the time necessary for decontamination.[109]

108 Addington, Lloyd, B. "Postattack Viability of the United States- 1975" Office of Army Engineers, National Academy of Sciences, et al. Symposium on Postattack Recovery from Nuclear War, Nov. 6-9, 1967

109 Minvielle, L. and Van Horn, Wm. "Recovery of Petroleum Refineries Contaminated by Fallout" U.S. Naval Radiological Defense Laboratory, USNRDL-TR-656 24 June 1963, Project sponsored by Office of Civil Defense

The procedures required for decontamination are carried in other Civil Defense literature, but refinery management can get some idea of the problem involved when he considers the job of giving every pipe, tower, vessel, tank, electric motor, etc., in the plant a good washdown preferably with detergent and water rinsing.

In the study cited, it was determined that availability of the refinery could be from 8 to 170 days after the time of the burst depending on the amount of fallout. Further, a small refinery exposed to low standard dose rate intensities could require 73 man days, and a large refinery exposed to a large dose rate could require 116,000 man days for decontamination. From the time of the burst, management of an undamaged plant needs to consider waiting time, decontamination time, and repair time caused by rapid shutdown in his prediction of recovery time. The size of the individual facility and the intensity of the dose rate will determine the decontamination time. If entry time to the plant can be delayed until the dose rate is 30 r/day, vital areas would need no decontamination, but only restricted entry would be possible.

Tank farm areas are so difficult to decontaminate that it is best to limit entry into these areas until radiation decays.

Decontamination Time- It was pointed out in a previous chapter the effects of radiation on the body. Radiation is accumulative. Not all persons have the same tolerance, but 200 roentgens total exposure over several weeks time is usually considered maximum.

Where most of the ground areas of a refinery are paved, hosing down with a fire hose is the major effort required to flush fallout debris away from the plant. This drain-off must go into a catch basin away from areas to which people will be exposed.

The time required for plant reclamation after experiencing radioactive fallout is generally estimated by the following formula:

$$\text{Time in days for reclamation} = \frac{\text{Effort in man-days}}{\text{Available manpower} \times \dfrac{\text{shift length in hrs.}}{24 \text{ hours}}}$$

In case the refinery (See Figure 103) can be cleared of fallout by a fire hosing, the least amount of time is required; where manual surface removal is required, the greatest manhours of effort is needed. The intermediate case probably will apply to most plants. By selecting the plant size in thousands of barrels of capacity and projecting this size upward to a point on the graph, one can read reclamation time or man-days at the left of the chart. Applying this value to the formula above, the estimated reclamation time can be determined.

Repair Time Because of Rapid Shutdown- Just how much warning time management will receive prior to an attack is a matter of guess. If the plant is within 20 or so miles of the target area, it is possible that because of the loss of electric power (and scared employees) there will be little or no lead time. The blackout experience discussed in Section I will be repeated. At most, no more than one hour warning can be expected and 15 minutes is likely to be it. Plants away from the blast area, of course, should have more time.

In the study cited above,[109] most plants visited would suffer some equipment damage, killed catalysts, cold feed stock, and many other complications which have to be corrected before starting-up can be initiated. Minvielle and Van Horn discuss this situation as follows:[109]

"A major factor in the situation under consideration is that, before taking shelter or evacuating, the personnel must first shut down the plant if it is to be recoverable. Abandoning the plant in panic would probably result in a total loss of the plant. Normally, it takes a significant amount of time to shut down a plant without damaging it; even a medium-sized plant may take as long as 48 hours. Shutdown involves the gradual dissipation of large amounts of energy in the form of high temperatures and high pressures in reaction vessels. In the emergency envisaged, the shutdown time may have to be sharply reduced to some time, say, between 1 hour and 6 hours. Rapid (or incomplete) shutdown will result in equipment damage. Very brief shutdown times- less than an hour- will result in unknown but considerable damage. In the event of hurried or uncontrolled shutdown, materials that were in a gaseous or liquid state in the processing will cool and solidify in the complex piping system, stills, and other equipment. If such materials are not removed, they may also corrode the equipment. Then, before repairs can be made, the replacement equipment, necessary materials, etc., must be available.

"Hence, before production can be resumed, personnel will have to recover the refinery by decontaminating the vital area, making repairs, removing solidified material and replacing some equipment.

"Fires could start and cause serious damage. Because of the unpredicability of the extent of fires in general, they do not lend themselves to quantitative studies. As a consequence, they have not been considered in this study."

Here again, exact recovery values will vary from plant to plant, but the formula given above applies generally. The values used in Figure 104 are the compilations of the results of the investigation discussed above. The values as suggested here, should be used only as a guide in estimating probably conditions at a specific refinery.

In Figure 104, by selecting the refinery size and projecting the value upward to the curve, the intersection, as read from the left, gives the total estimated man-days required to repair an installation and to ready it for renewed activity. A man-day is the work time of one man equivalent working 24 hours, or three men working 8 hours each. *No bomb damage is considered;* just repairs required by rapid shutdown.

Therefore, after a nuclear blast, the refinery management of an undamaged plant must plan on the waiting time after the shock for fallout to reduce to human tolerances to radioactivity, the decontamination time involved to remove the fallout debris, and the repair or preparation time required to again start the plant in operation. At the conclusion of the Minvielle and Van Horn study, the following observations were made:

"1. *General Survival Plan.* A few refineries have a general survival plan; most of them do not. If an attack were to

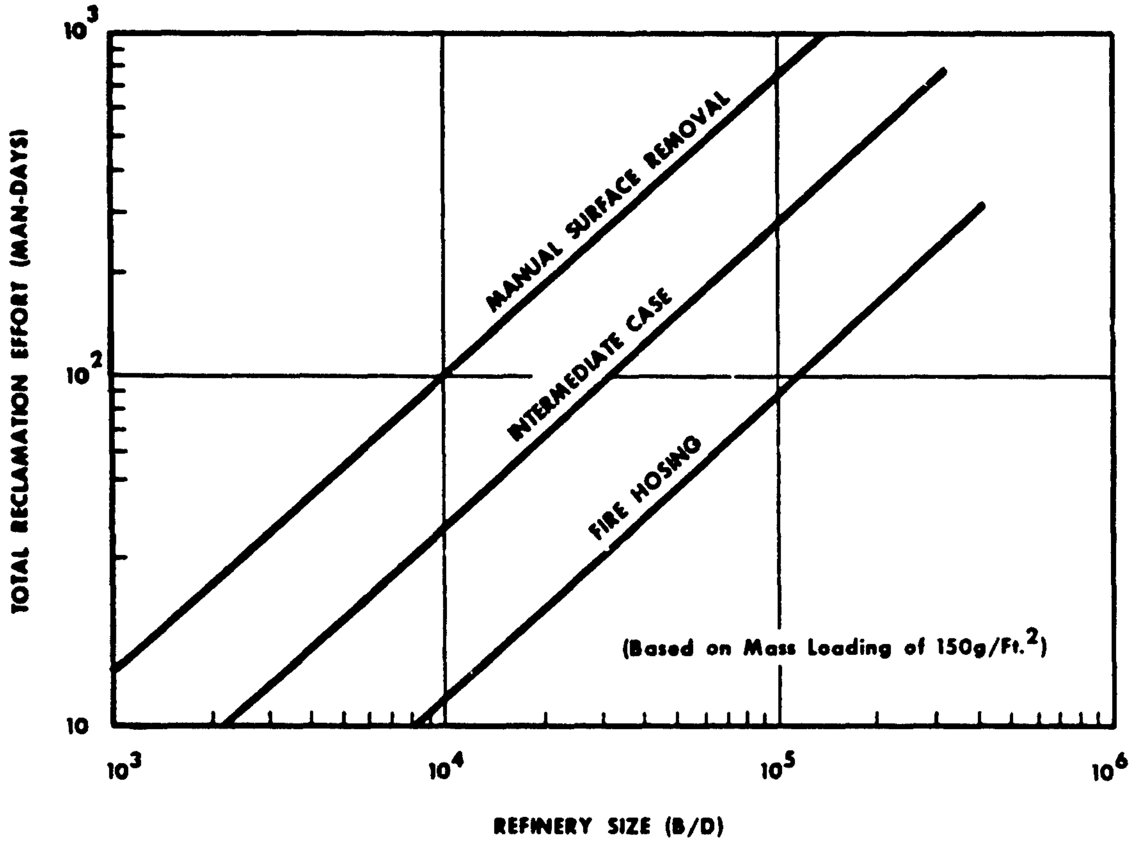


Figure 103. Total Reclamation Effort vs Refinery Size[109]

occur in the near future, one could not at present visualize personnel of these refineries surviving or making a concentrated effort to save their plant. One can foresee only chaos and wild flight, with abandonment of the operating plant.

"If a serious effort is contemplated for the protection of personnel and the recovery of refineries, it is recommended that a survey be made in each refinery to evaluate the effectiveness of certain buildings as fallout shelters. In the medium-sized refineries, there usually are many concrete and brick buildings that could be modified to provide adequate protection. In addition, a study should be made of evacuation possibilities. The thought here is that a small group would remain in the refinery to shutdown the plant before the arrival of fallout and then go to shelters near their work locations. This measure would preclude abandonment of the operating refinery and its resulting complete loss, and would tend to minimize fast shutdown damage and the subsequent repairs that would be required. If feasible, the other personnel would evacuate the refinery and the potential fallout area before fallout arrival.

"In drawing a general survival plan, it is recommended that refineries located near large bodies of navigable water investigate the possibility of using ships for both evacuation and shelter. The radiation intensities aboard a ship in contaminated water would be much less than those on contaminated land because of settling and dispersion of radioactive fallout in the water, the attenuation of radiation by the water, and the shielding provided by the ship's structure. Also, the ships serve as adequate staging areas for decontamination and repair work, and the water would offer a much less hazardous means of travelling to and from the refinery.

"2. *Nucleus of a Recovery Force.* In England and Germany during World War II, a central group of personnel was trained to initiate recovery of bombed plants and was sent to bombed plants as the need arose. This practice proved successful. In case of nuclear attack, refinery personnel may

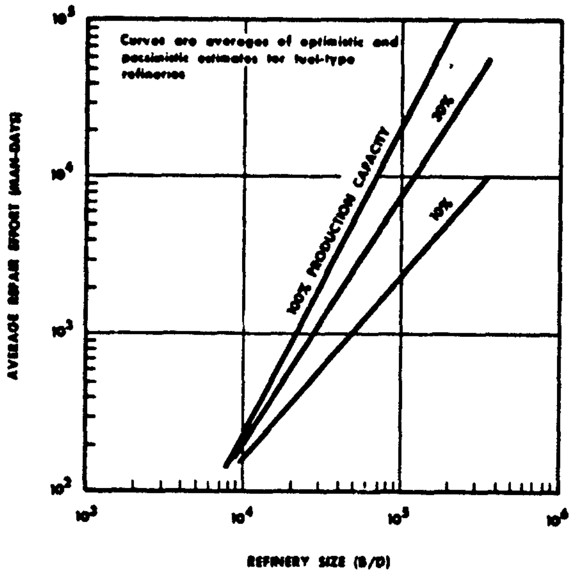


Figure 104. Average Repair Effort vs Refinery Size For 1-Hr Shutdown Time And Three Production Capacities

not be depended on to cope wholeheartedly and efficiently with the recovery and resumption of operations of the plant because of more pressing personal problems. Training and use of such a group for recovery would prove particularly effective in speeding up recovery.

"3. *Training of Plant Personnel.* Most of the personnel in refineries have only a general familiarity with the characteristics of radioactive fallout, the hazards and biological effects of ionizing radiations, and the countermeasures that can be taken to reduce radiation hazards. In order that refinery personnel may be able to carry out the necessary countermeasures effectively, they should undergo a period of instruction and training in the fundamentals of the above subjects. At least, key personnel should undergo such instruction and training so that they can initiate protective measures and direct the recovery operations.

"4. *Emergency Shutdown Study and Personnel Drills.* Because of the large repair effort that may be required as a result of fast emergency shutdown, it is recommended that a study be made to determine the optimum procedure for carrying out fast emergency shutdown of various types of refinery, and that personnel be instructed and drilled in such procedure.

"5. *Radiological Reclamation of Industrial Complexes.* Existing data on radiological reclamation are based on tests conducted in relatively simple areas, such as paved open spaces and uncomplicated residential mock ups; these data include the determination of methods and procedures for reclamation, the estimation of logistic requirements and rates of performance, and the evaluation of the effectiveness and overall reduction of intensity of reclamation techniques. Industrial sites, such as one encounters in a petroleum refinery, present a much more difficult and complex problem. One cannot extrapolate from currently available data to industrial sites of this type and have any confidence in the results. To obtain data that can be used with an acceptable degree of confidence, it is recommended that reclamation tests of the type indicated above be conducted on various types of industrial sites.

"6. *Preparation of Refinery Grounds.* In many of the refineries visited, the task of decontaminating the vital areas would be very difficult because of the type of existing surfaces. Certain such surfaces could be easily improved. For instance, in new paving or in resurfacing use of a slightly different method of paving would result in a surface that would considerably simplify decontamination.

"7. *Availability of Critical Equipment and Repair Materials.* A study conducted by the U.S. Air Force indicates that obtaining certain critical refinery equipment and repair materials could result in long delays of the order of 9 to 27 months. To expedite recovery of refineries, it is recommended that consideration be given to a faster means of obtaining critical equipment and materials than that indicated in Ref. 7.

"8. *Vulnerability and Repairs of Large and Small Refineries.* The analysis contained in Appendix F* reveals that large refineries are much more vulnerable to fast shutdown times than smaller refineries. In case of an expected attack and if a choice is needed and possible, it is recommended that the larger refineries be shut down in advance of the attack and the smaller refineries be allowed to continue operations. In addition, if a group of refineries were damaged due to a fallout event of the type considered in this study and if the shutdown times are known to be approximately the same, recovery of the smaller refineries should be performed first, other factors being equal."

Blast Damage Repair

A plant near a target area will be subjected to the many destructive forces released by the exploding nuclear weapon. These were discussed in Chapter VIII. Since no war effort can extend for more than a few days without a generous flow of petroleum products, it is essential that damaged equipment be put on-stream as fast as possible.

Walker[91] points out that after a blast, the decision to rebuild or repair a refinery or natural gasoline plant will hinge on what products are immediately needed, the availability of labor, equipment, supplies, and the extent of damage to the facility. Its location or accessibility to transportation would certainly be an added factor for consideration. Refinery damage in general can be related to the blast pressure (overpressure) to which the installation was subjected. Figure 83 and Tables 40, 43, 44 and 45 show the extent of damage such pressures can cause. Walker[91] points out the following:

After 0.3 to 0.5 psi overpressure, a refinery can produce the same proportion of products but only at 70% of its initial capacity.

(*Not reproduced here)

After 1.0 psi overpressure, a refinery temporarily shuts down, but with minor repair to process controls, it can operate at about 50% of initial capacity.

After 1.5 psi overpressure, a refinery is totally shut down, primarily because of process control damage by roof collapse in control rooms. (See Chapter VII). Figure 83 shows the damaging effects of higher overpressures.

Debris Removal

The repair of a refinery cannot take place until first the damaged equipment is removed. It is possible that some removal of debris will take place simultaneously with decontamination. Bull dozers, cutting torches, backhoes, graders, cranes, trucks and labor, all will make a concerted effort to clear the area. Engineers, constructors, and management will be feverishly working to start reconstruction.

Personnel and Equipment Exchange

It is possible in some cases where equipment is not available, that a nearby plant more severely damaged will be used as a source of readily available materials and equipment. It is probable that engineers and labor will be exchanged from other plants in mutual aid to get a selected plant into operation as fast as possible. Where materials and supplies cannot be readily obtained, the local EPGA representative will lend assistance.

Stock Piles - Undamaged equipment in warehouses of suppliers and in neighboring refineries will be of great value in the reconstruction period. Planning for such emergencies can be of inestimable value. A list of critical materials is given in the Tables of the Appendix.

Order of Repair - The selection of the sequence of repair will be dependent on the products needed at this time and amount and type of crude supply. A substitute crude might be required. Probably a supply of gasoline, kerosene, (jet fuels) and diesel fuels will be in short supply. On this basis, the following will be the order of repair:

(1) Crude Topping Unit
(2) Cracking Processes
(3) Processing Units that upgrade products
(4) Supporting Units

It is probable that specialty plants will supply sufficient lubes and greases to meet emergency needs.

Time Required for Repair of Blast Damage - It is evident that the time of repair not only depends in specific cases on the extent of damage, but on the availability of labor, supplies and equipment. If lines can be laid to a nearby plant, it may be possible to exchange feed stocks where each might have different units capable of operation.

Rebuilding time is slow, and even in peace time, it is a disappointing experience when the delivery of a critical part of the installation is delayed. This situation is certain to be magnified in postattack conditions. Cannibalization of other damaged plants could furnish hard-to-get parts.

Walker, assuming normal delivery times, made time of repair estimates on the basis of labor requirement. His work is shown in Table 49 and in Figure 106. Since crude topping units would most likely be first to be repaired, it is probable that portions of some plants could be put into operation before the facility is completely rebuilt. Because of the interdependence of processes within a complex refinery, there could be some critical balance problems develop under such procedure. Operation in war time, however, is not necessarily unexpected to follow peace time practice.

Cost of Repairs - Any estimate of cost under war time conditions is no more than a guess, for economic conditions could be considerably different than normal. The cost of rebuilding or repairing will depend on the skill of the workers required to do the work, plus materials. It is estimated that about 60% of the repair costs will be labor costs. The skills probably needed to repair an installation are shown in Table 50.

Based on an average labor cost of $6.10 per hour, Tables 51 and 52 and Figure 107 show the possible cost to restore various units to operation. Figure 107 compares repair costs to new construction cost.

These calculations are meant only to be a general estimate based on construction costs of the late 60's and are given with full knowledge that war time conditions could be considerably different. Should government controls be in effect at the time, it is possible that cost could actually be lower than shown. The values given, however, should have relative significance.

Security

The problems of plant security have in recent years continued to increase in both need and importance to management. Security no longer can be thought of in terms of an old retired man sitting at the front gate. Extensive planning by the combined effort of experts in various fields is now required by all of the critical industries.

Security in industry cannot be measured in terms of so much equipment or in terms of so many police or firemen. The entire security system of a modern refinery is a complete program from guard controls, fire and theft prevention, disaster control, employee education as to the protection of proprietary information, and other important documents, including audits, blueprints and critical information.

Sabotage prevention is of utmost importance, and in time of war, this job alone could tax the relatively small security staff of the average plant. Disaster protection planning, including the protection of personnel and equipment in time of war, is of great importance to security.

Security is a top management job. No modern operation can long endure without some of their best "brains" working in this endeavor.

Healy,[110] lists three present day hazards to be considered in the design of physical controls.

1. Theft of company assets or property
2. Espionage involving both company and government secrets

110 Healy, Richard J. "Design for Security" Aerospace Corp. John Wiley & Sons, Inc. February 1968

Table 49. Repair Requirements, by Refinery Type

Refinery Type	Capacity, B/D	Labor in Man-Days			
		0.5 psi	1 psi	5 psi	10 psi
Large fuel	78,000	36,000	128,000	178,000	292,000
	150,000*	70,000	245,000	341,000	556,000
Small fuel	24,000	7,000	24,000	36,000	77,000
Complete processing	194,000	82,000	289,000	402,000	640,000
Asphalt	12,000	3,000	11,000	16,000	28,000
	14,000*	4,000	13,000	18,000	31,000
Asphalt and lube	7,000	2,000	6,000	10,000	22,000
Lube	4,000	1,000	4,000	6,000	18,000
	27,000*	7,000	25,000	37,000	72,000

*Included to determine the effect of refinery size variation on repair requirement.

(After Walker)

Table 50. Craft Required to Repair a Refinery Damaged by Various Overpressures

psi	Equipment Repair	Craft	Comments
0.3–0.5	Cooling tower	Carpenter	Outer louvers broken
0.5	Instruments	Glazier	Glass fronts broken
1.0–5.0	Structure and and tank	General construction Metal fabrication Electrician/instrument	Structures deformed and "soft" equipment damaged
5–10	Equipment relocation	General construction Metal fabrication Machining Electrician/instrument	Equipment displaced from foundation
10 and higher	Nearly total rebuilding	General construction Metal fabrication Machining Electrician/instrument	"Hard equipment suffers damage

Table 51. Summary of Repair Estimates[74]

Unit	Capacity b/d	Over-pressure psi	Principal Damage	Repair time project days	Estimated Field Labor man-days: To repair	Estimated Field Labor man-days: To build complete new unit	Cost of repair materials 1965 dollars
Crude Still	80,000	3.5	Collapse of attendant structure	151	4,270	40,000	330,000
Crude Still	80,000	7	Collapse of atmospheric and vacuum towers and attendant structure	277	17,630	40,000	1,370,000
Atmospheric furnace: crude still	80,000	6.5	Collapse of furnace	163	3,170	2,400	246,000
Fluid cat cracker	31,000	12	Collapse of fractionator and reactor. Deformation of regenerator support	251	20,700	30,000	1,610,000
Vapor recovery unit	–	6	Overturn absorber and lean oil still towers and supports	204	7,630	7,000	592,000
Controlhouse: FCC and alkylation units	–	1.0	Collapse switch gear roof, secondary missile damage to sw. gear and instruments	188	1,360	3,000	105,000
100' Dia x 48' high floating roof welded steel storage tank 50% to 90% filled	67,140 bbl	5	Leakage of contents into diked area. Rupture of bottom to shell joint. Roof jammed. Wind girders and stairs deformed.	39	160	300 (1 tank exclusive of foundation)	6,200

Table 52. Repair Cost After 10psi Overpressure[91]

Refinery Type	Capacity, B/D	Labor Required After 10 psi* (man-days)	Labor Cost † ($000's)	Calculated Total Cost ‡ ($000's)
Large fuel	78,000	292,000	$14,200	$23,700
	150,000	556,000	27,100	45,200
Small fuel	24,000	77,000	3,800	6,300
Complete processing	194,000	640,000	31,200	52,000
Asphalt	12,000	28,000	1,400	2,300
	14,000	31,000	1,500	2,500
Asphalt and lube	7,000	22,000	1,100	1,800
Lube	4,000	18,000	900	1,500
	27,000	72,000	3,500	5,800

*Man-days rounded to nearest 1,000.
†Rate = $6.10/hr X 8 hr/day = $48.8/day.
‡Labor Cost ÷ 0.6.

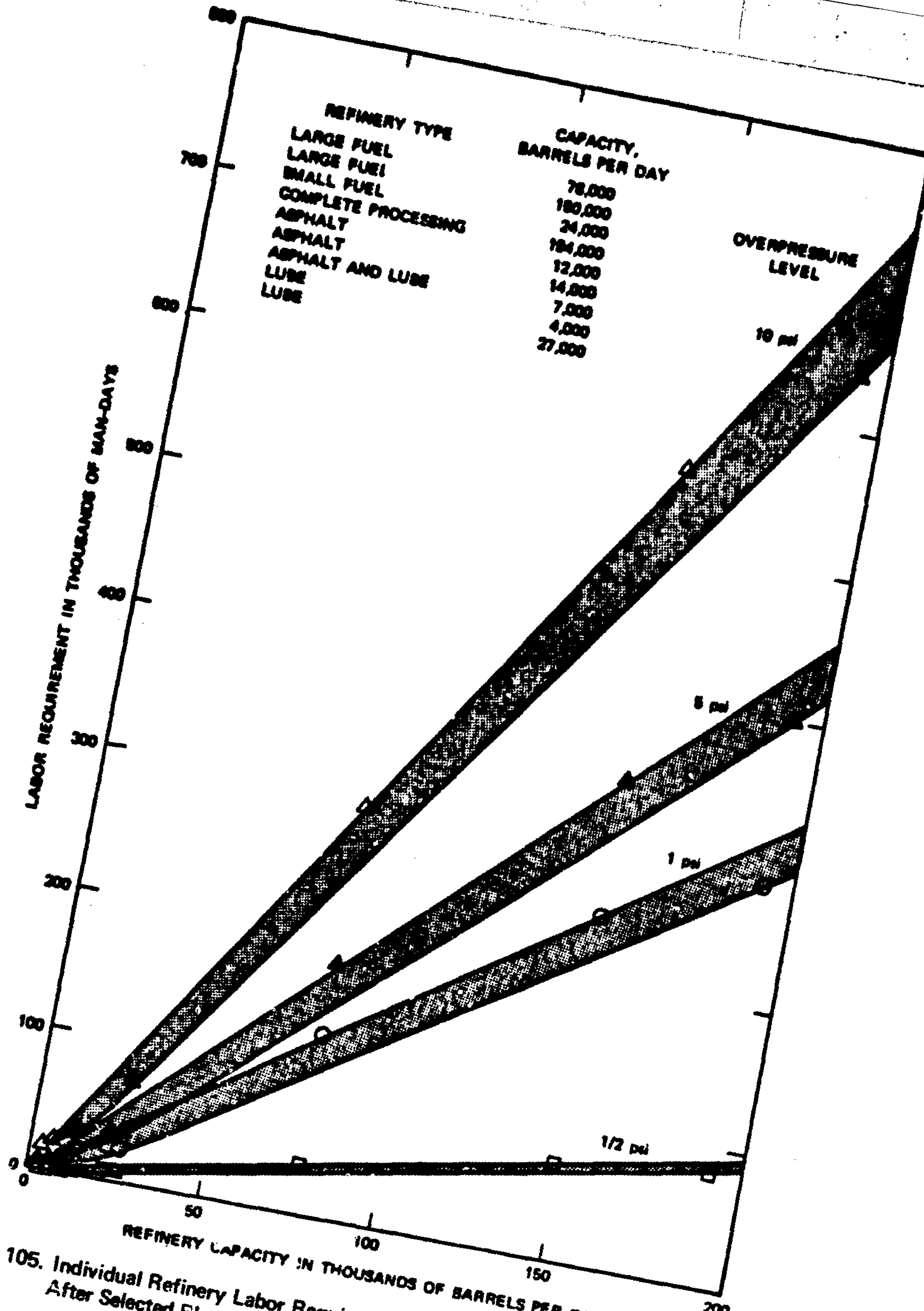


Figure 105. Individual Refinery Labor Requirements To Restore 100 Percent Capacity After Selected Blast Overpressure Levels[91]

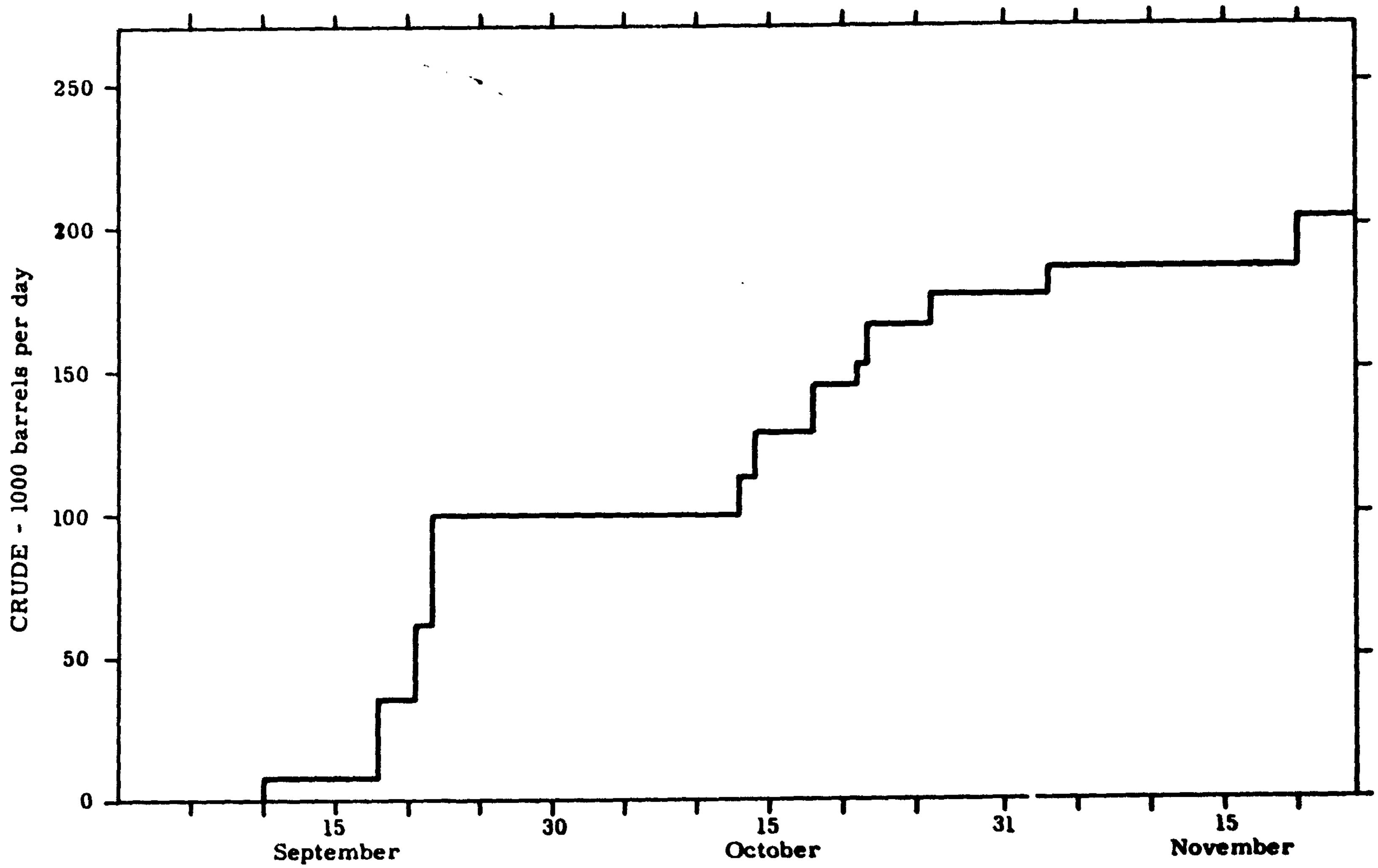


Figure 106. Recovery of Production Following the 1955 Whiting Fire—American Oil Co.
(Source: Advance Research, Inc[74])

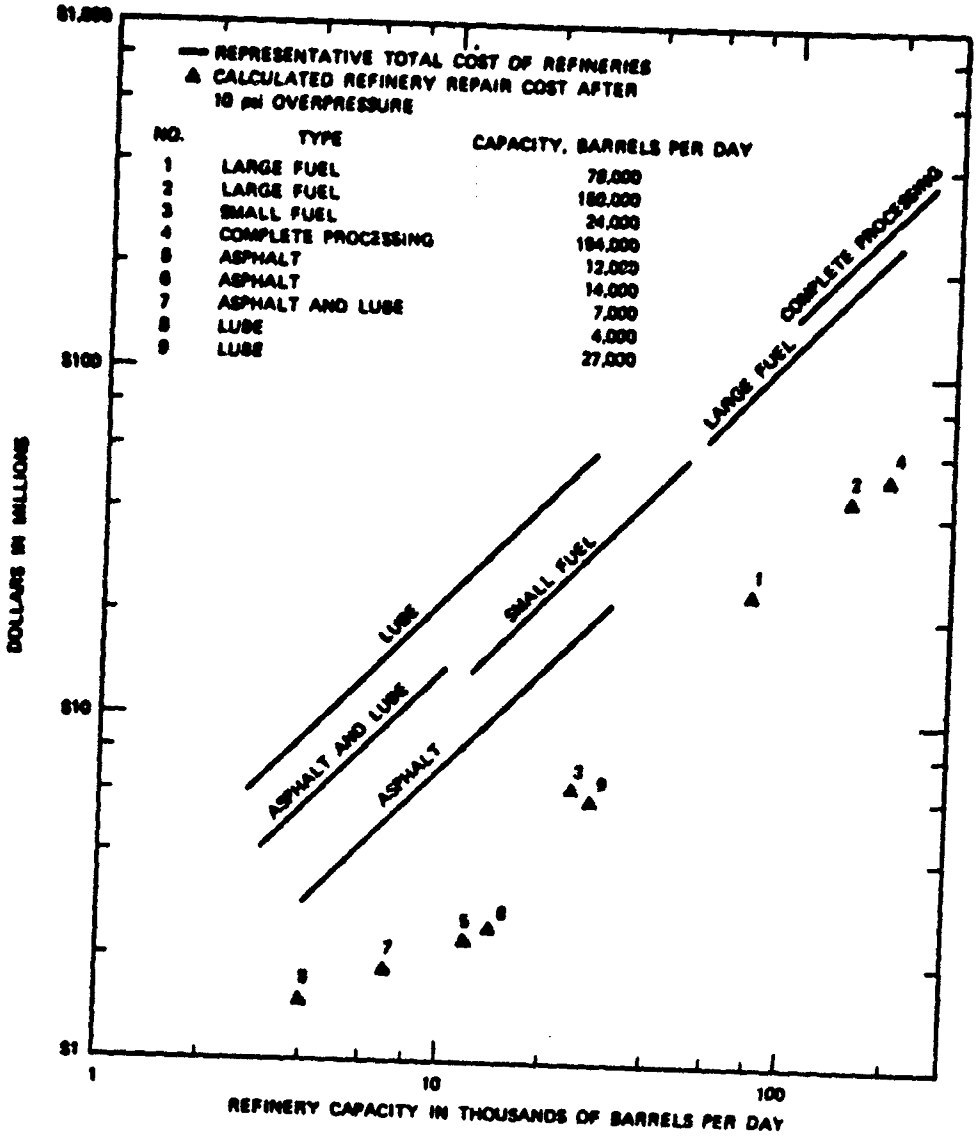


Figure 107. Cost to Restore Refineries to 100 Percent Capacity After 10 psi Blast Overpressure, Compared With New Refinery Construction Cost[91]

3. Sabotage or man-caused emergencies

These problems will be multiplied by some large factor in time of war. The better the planning and the execution of security is done today, the better such plans can serve in time of war.

Much has been written on this general subject, and much work is being done in this field. The American Society for Industrial Security with its full time staff and many thousand members along with almost every governmental agency are not only working to reduce lawlessness and industrial losses and damage, but also are working with enthusiasm and diligence to reduce as much as possible the destruction of our industries in time of war.

Observations

Healy[111] states:

"Every business, industry, institution, or government facility, regardless of size or location, is threatened daily by a variety of potential disaster situations which could seriously damage the organization or even be so catastrophic as to destroy it completely. A disaster has been defined as 'a sudden unforeseen, and extraordinary misfortune, an unlucky chance of occurrence'. The hazardous potential of disaster is often

111 Healy, Richard J. "Emergency and Disaster Planning" John Wiley & Sons, Inc. March 1969

Figure 108. I only said, "This seems to be a poor time to begin to develop a disaster plan."

(Source: John Wiley & Sons Inc. N.Y.)

overlooked by management representatives, because this area usually does not manifest itself as an operational problem encountered during the regular business day. Because of this, many organizations give little or no thought to planning for disaster . . . .

"A plan will not guarantee that a disaster will not develop because emergency situations, especially those resulting from natural phenomena, usually cannot be prevented. However, actions taken to cope with an emergency situation as it begins to develop may prevent a disaster from developing into a tragedy . . .

"An emergency is a situation characterized by one or more of the following conditions: shortage of time, personnel, material resources.

"An emergency is significant if it represents a hazard to life or material, or if it contributes to human suffering. Shortage of time can be minimized only by advanced planning. Shortage of personnel can be minimized only by advance recruiting and training. Shortage of resources can be minimized only by advance stockpiling, inventory of available resources, and by mutual aid agreements.

"Some emergency situations such as hurricanes and floods are predictable in advance. Although the destructive force cannot be avoided, it is possible to take advantage of the warning time available to minimize the damage of the initial impact. On the other hand, there may be no advanced warning such as in the case of an earthquake or explosion. In such instances, it may not be possible to avoid or decrease the human or material cost of the initial impact. However, by placing an emergency plan into operation immediately, it may be possible to avoid additional costly damage."

LIST OF REFERENCES

1. Warren, E.C. "Justification for Blast-Resistant Control Center Buildings" API Subcommittee on Facilities, Division of Refining. Los Angeles, Calif., May 15, 1967.

2. Jacobs, R.B. "Occurrence and Nature of Hydrocarbon Detonation" API Division of Refining. Chicago, Illinois, November 9, 1959.

3. Stormont, D.H., "U.S. Refineries on Big New Capacity - Building Binge" Oil and Gas Journal, January 27, 1969, p. 89.

4. American Insurance Association "Hazards Survey of the Chemical and Allied Industries" Technical Survey No. 3 - Engineering and Safety Dept. - Division of Technical Services - 1968.

5. Oil and Gas Journal - March 24, 1969 - "Capacities reported January 1, 1969"

6. U.S. Dept. of Commerce "A Proposed Nationwide Natural Disaster Warning System (NADWARN)" Environmental Science Services Administration Oct. 1965.

7. Federal Disaster Act Public Law 81-875

8. Dept. of Defense - OCD - "Hurricane Carla" December 22, 1961

9. U.S. Dept. of Commerce - Notes on Hurricanes - April 1966, LS6002 Rev.

10. U.S. Dept. of Commerce - "Some Devastating North Atlantic Hurricanes of the 20th Century" Environmental Science Services Administration April 1966 CS 6506 Rev.

11. Factory Special Report "Now's the Time to Prepare for Hurricanes" Management and Maintenance Plant Operation Library No. 159 McGraw Hill Pub. Co. August 1956.

12. Glasstone, Samuel "The Effects of Nuclear Weapons" U.S. Dept. of Defense, U.S. Atomic Energy Commission April 1962.

13. U.S. Dept. of Commerce "Tornado Preparedness Planning" Environmental Science Services Administration, Weather Bureau March 1968.

14. Weather Bureau "It Looks Like a Tornado" Handbook for Tornado Network Observers U.S. Dept. of Commerce, Washington, D.C. 1953.

15. Dept. of Commerce "Aviation Weather" Federal Aviation Agency Flight Standards Service Washington, D.C. 1965, p. 104

16. U.S. Dept. of Commerce "Tornado Preparedness Planning" op. cit. p. 28

17. Dept. of Commerce "Aviation Weather" op. cit. p. 112.

18. U.S. Dept. of Commerce "Earthquakes" Information Bulletin NEIC, ESSA, Vol. 1, No. 9, November 1967.

19. Dept. of Defense "The Alaskan Earthquake" Office of Civil Defense May 1964.

20. State of California- "Geology of Southern California" Division of Mines, Dept. of Natural Resources- Bulletin 170- Vol. 1, 1954. Many other references are given in this bulletin.

21. American Association of Petroleum Geologists- Tectonic Map of the United States- Tulsa, Oklahoma.

22. Los Angeles Ordinance No. 100,347 amending Article 1, Chapt. 9 Los Angeles Municipal Code- August 26, 1952.

23. Hollis, Ed. P.- "Bibliography of Engineering Seismology" Earthquake Engineering Research Institute- San Francisco, Calif. 1961.

24. National Petroleum Council- "Impact of Electric Power Outages on Petroleum Industry" 1966.

25. Huffman, W.C.- "Power Blackout Incidents and Plans Against Recurrence" American Petroleum Institute Div. of Refining- Meeting May 15, 1968.

26. Defense Electric Power Adm.- "Civil Defense Preparedness in the Electric Power Industry" U.S. Dept. of Interior- p. 13 A- March 1966.

27. National Petroleum Council- "Critical Materials Requirements for Petroleum Refining" Washington D.C. March 1966.

28. National Petroleum Council- "Report on Maintenance and Chemical Requirements for U.S. Petroleum Refineries and Natural Gasoline Plants" Washington D.C. 1961.

29. Winger, John G., Emerson, John D., and Gunning, Gerald D.- "Outlook for Energy in the United States" The Chase Manhattan Bank, N.A. New York. October 1968.

30. Reproduced from National Academy of Sciences- "Role of Petrochemical Industry in Recovery from Nuclear Attack and Recommended Plans to Reduce Vulnerability" Advisory Committee of Emergency Planning. December 1961.

31. Pryor, Takata, Bennett, Decarle, et al- "Food from Petroleum" Hydrocarbon Processing- March 1969- pages 95-112.

32. Couch, Virgil L.- "How to Prepare for Civil Defense in Industry" Industrial Security, July 1962, page 8.

33. Couch, Virgil, L.- "The National Program for Industrial Survival" Civil Defender- Industrial Issue- page 12.

34. Pasma, T.K.- "Assessment of Plant Vulnerability" U.S. Dept. of Commerce- Article in Civil Defender- Industrial Issue- page 15.

35. Kesler, Frank J.- "Determining Vulnerability of Your Plant to Attack" Industrial Security July 1962, page 24.

36. Stocker, Wm. M.- "Deconcentration of Production" Civil Defender- Industrial Issue- page 35.

37. Couch, Virgil L.- Panel- "Professional Civil Defense Training Available to Industry" Proceedings American Society for Industrial Security- Philadelphia, Pa. September 22, 1966- page 117.

38. Spiegelman, Arthur- "Risk Evaluation of Chemical Plants" 64th National Meeting American Institute of Chemical Engineers- New Orleans, La. March 1969. Paper 25 A- Also Footnote 4.

39. Cherney, Marvin- "Flame Inhibition of Vapor Air Mixture" American Institute of Chemical Engineers Meeting- New Orleans, La., March 1969- Paper 29 A.

40. Gilmore, Charles- "The Texas City Industrial Mutual Aid System" An address before the Industrial Defense Symposium- May 5, 1965. The Provost Marshall Hdq. 4th U.S. Army- Ft. Sam Houston, Texas. Reprinted by OCD.

41. Ducommun, Jesse C.- "6:12 at FHU-700" API- Chicago, Ill. Nov. 14, 1956.

42. Jacobs, P.B., Bulkley, W.L., Rhodes, J.C., and Speer, T.L.- "Destruction of a Large Refinery Unit by Gaseous Detonation" Chemical Engin. Progress- December 1957- Vol. 53- No. 12- page 565.

43. Pipkin, O.A.- "Detonation- Old Processes are not Immune" Amer. Petroleum Institute- Chicago, Ill. Meeting- November 1959.

44. Robinson, Clark Shove- "Explosions- Their Anatomy and Destructiveness" McGraw-Hill Book Co., Inc. 1944- page 11.

45. Brasie, W.C. and Simpson, D.W.- "Guidelines for Estimating Damage Explosion" Loss Prevention, a CEP technical manual. American Institute Chem. Engin. Symposium- St. Loui, Mo. 1968- page 91.

46. Glasstone, Samuel- "The Effects of Nuclear Weapons" U.S. Dept. of Defense and U.S. Atomic Energy Commission- Revised Edition- 1964.

47. Spiegelman, Arthur- "Autopsy of an Explosion" Fire Engineering- October 1967- page 52.

48. Brinkley, Stuart R., Jr.- "Detonation of Explosion Yield of an Exothermic or Detonable Reaction" Loss Prevention Conference- 64th Meeting AIChE- New Orleans, La., March 1969.

49. Van Dolah, P.W.- "Detonation Potential of Nitric Acid Systems" Loss Prevention Symposium- 64th Meeting AIChE- New Orleans, La.- March 1969

50. Ginsburgh, I. and Bulkley, W.L.- "Hydrocarbon-Air Detonations" Industrial Aspects- Chem. Engin. Progress- February 1963, page 82.

51. Zabetakis, Michael G.- "Flammability Characteristics of Combustible Gases and Vapors" U.S. Bureau of Mines Bull. 627, 1965- TN23U4 No. 627 622.06173.

52. Van Dolah, Robert W., Zabetakis, Michael G., Burgess, Davis S., and Scott, George S.- "Review of Fire and Explosion Hazards of Flight Vehicle Combustibles" U.S. Bureau of Mines Inf. Circ. 8137- 1963. Page 16.

53. Klein, Howard A.- "The Effects of Cabin Atmosphere on Combustion of Some Flammable Aircraft Materials" WADC Technical Report 59-456. April 1960.

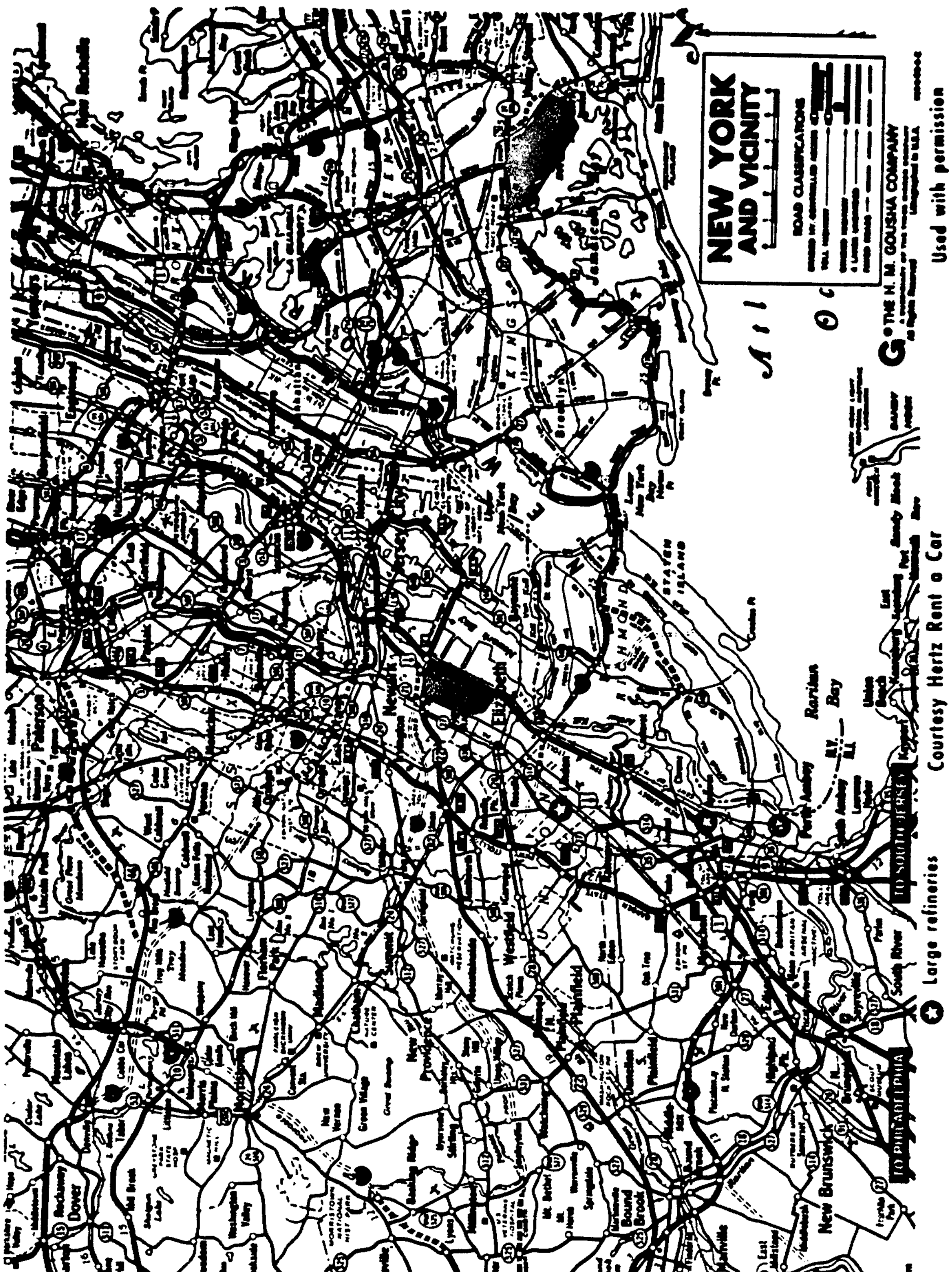
54. Bradford, W.J. and Culbertson, T.L.- "Design of Control Houses to Withstand Explosive Forces" AIChE Meeting- Houston, Tex. Feb. 1967.

55. Reider, Roy; Otway, H.J.; and Knight, H.T.- "An Unconfined, Large Volume Hydrogen/Air Explosion" Pyrodynamics- 2-249-261- 1965.

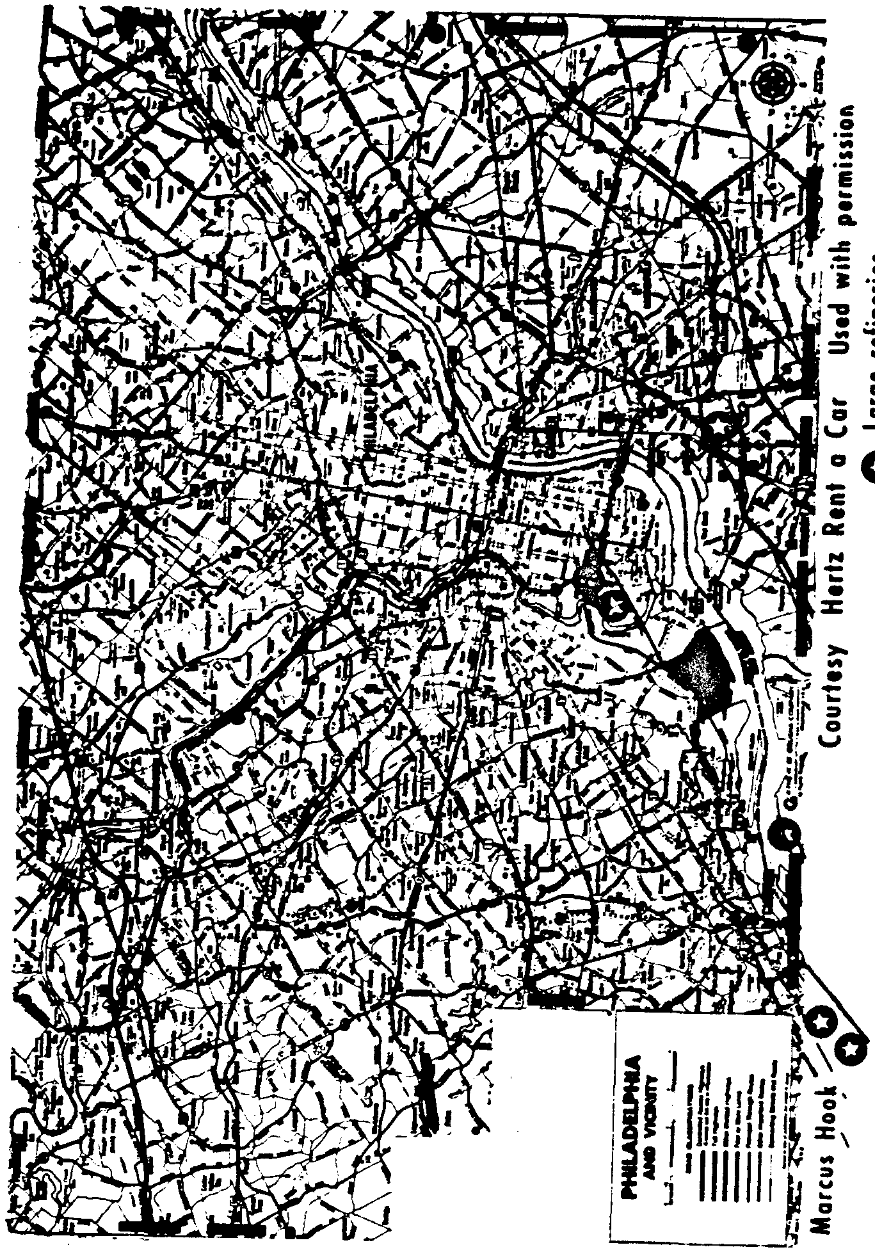
Preceding page blank

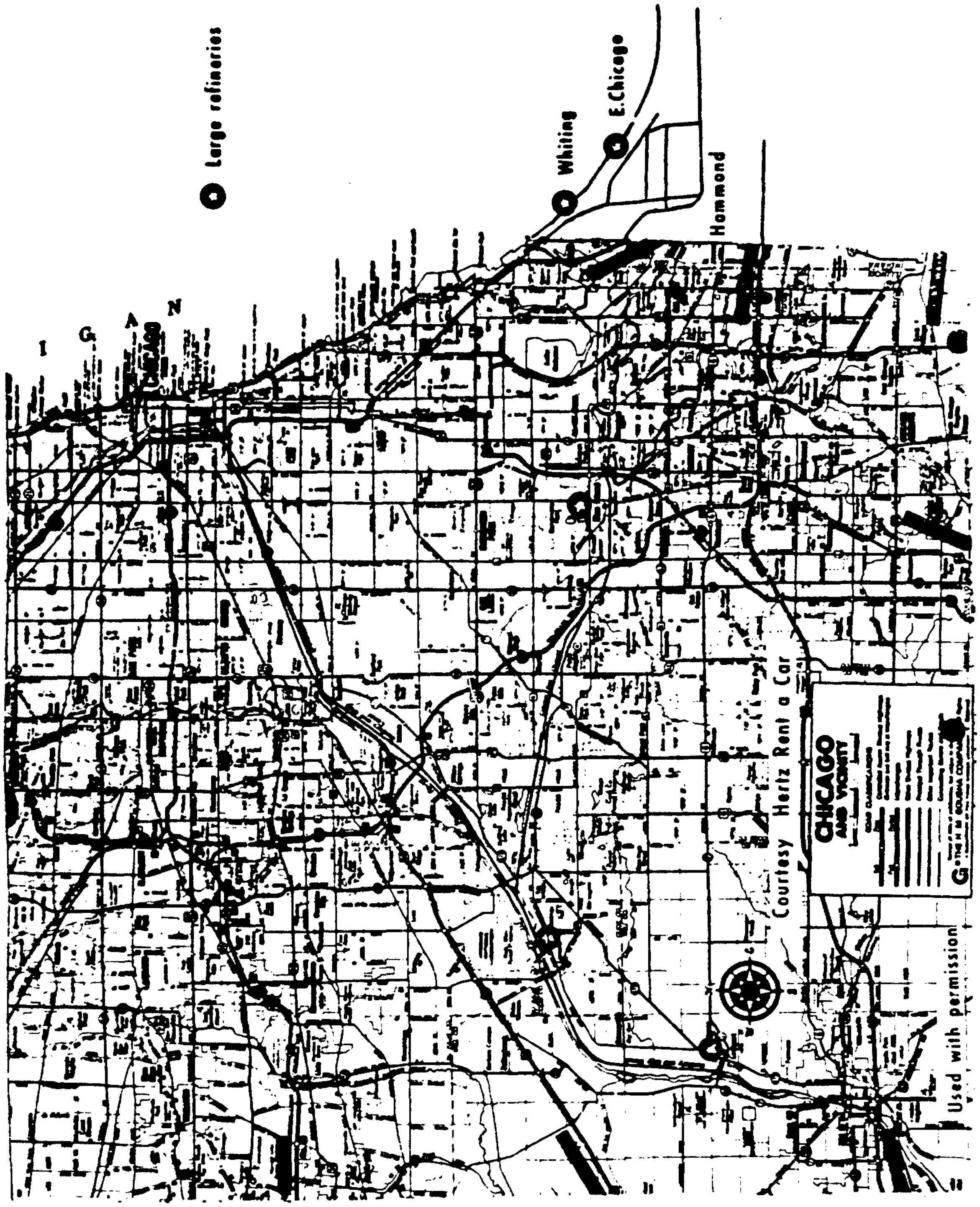
56. Bulkley, William I. and Jacobs, R.B.- "Hazard of Atmospheric Releases of Large Volumes of Hydrogen" API Facilities Subcommittee- Oct. 4, 1966.
57. Gesler, Roy L. and Churchill, Stuart W.- "Detonation Characteristics of Hydrogen-Oxygen Mixtures at High Initial Pressures" American Inst. Chem. Eng. Journal- Vol. 6- No. 3- September 1960.
58. Zabetakis, M.C. and Burgess, D.S.- "Research on the Hazards Associated with the Production and Handling of Liquid Hydrogen" U.S. Bureau of Mines- R15707- U.S. Dept. of Interior- 1961.
59. Woodworth, Miles E.- "Whiting Refinery Fire" National Fire Protection Association Quarterly- October 1955.
60. Woodworth, Miles E.- "Texas Refinery Tragedy" report by National Fire Protection Association. Reprint Q 50-3 from October 1956 NFPA Quarterly.
61. Fire Journal- "Oil Refinery" New Article- May 1968- page 8.
62. Woodworth, Miles E.- "Oil Froth Fire at Signal Hill Refinery" Reprint Q 52-5 October 1958- NFPA Quarterly.
63. National Brandpreventie Institute- "Shell Refinery Fire- The Netherlands" and Woodworth, Miles E.- Fire Journal September 1968, page 110.
64. Police President of Hamburg- Report by the Police president of Hamburg and local air protection leader of Hamburg on the large scale raids on Humburg in July and August 1943- Experiences- Vol. 1- Report Translation page 38- as reported by Office of Civil Defense, Fire Aspects of Civil Defense- TR-25 July 1968.
65. Ducommon J.C.- "A Pattern for Process Safety" API 40th Annual Meeting- Preprint A-13, November 14, 1960.
66. Robinson, H.S.- "Is Operating Process Safety Keeping Pace with Changing Technology?" API 32nd Midyear Meeting- Los Angeles, California- May 16, 1967- Preprint No. 41-67.
67. Austin, C. Henry- "Risk Analysis and Safety" American Petroleum Institute 40th Annual Meeting- Div. of Refining- November 14, 1960, A-12
68. Symonds, Edward- "New Tanker Trends" Energy Memo- First National City Bank- Petroleum Department- July 1968.
69. Johnson, D.M.- "The Billion Gallon Tank Farm Design for Safety" Amer. Inst. Chem. Eng.- New Orleans Meeting- March 1969- Reprint 30 c.
70. Rinne, John E.- "Oil Storage Tanks" U.S. Dept of Commerce- Environmental Science Services Administration.
71. Flammable and Combustible Liquids Code (1966)- National Fire Protection Association, 60 Batterymarch Street, Boston, Mass. 02110.
72. Welded Steel Tanks for Oil Storage- (Third Edition) July 1966, and Supplement to API Standard 650 (Third Edition) December 1967- American Petroleum Institute, 1271 Avenue of the Americas, New York, N.Y. 10020.
73. Fire Prevention Code- 1965 Edition and 1966 Revisions- American Insurance Association- 85 John St., New York, N.Y. 10038.
74. Fernald, Olaf, H. etal- "Critical Industry Repair Analysis, Petroleum Industry" Advance Research, Inc.- OCD Subtask 3311A- October, 1965.
75. Ducommun, Jesse C.- "Engineering for Safe Operation" American Oil Co. Booklet No. 8- 2nd edition- page 51- 1966.
76. Allan, Donald S. and Athens, Peter- "Influence of Explosions on Design" Arthur D. Little, Inc.- Am. Inst. Chem. Eng.- Loss Prevention Manual- Vol 2- p. 103- 1968.
77. Czerniak, Eli- "Foundation Design Guide for Stocks and Towers" The Fluo Corp., Ltd.- Hydrocarbon Processing Sect I- p. 95- June 1969.
78. Humble Oil and Refining Company- "Buildings Designed for Shock Resistance" Baytown Engineering Standard No. 15- 01-3P.
79. Noyes and Co., Inc.- "Hardened Building Withstands Overpressure of 20 psi" A news release for Industrial National Bank, Providence, Rhode Island- July 7, 1963.
80. Department of Defense- "Underground Plants for Industry" Dept. of the Army, Office of Engineers- AGO 1018313- Reprinted January 1962- page 5.
81. Couch, Virgil L.- "Survival Plans Your Company Can Use" Nation Business- Report- Department of Defense OCD- Dec. 1961.
82. RCA- "Atomic Radiation" Government Service Dept- Radio Corporation of America Revised, 1958.
83. Martin, Thomas L. and Latham, Donald C.- "Strategy for Survival" The Univ. of Arizona Press, Tuscon, Arizona- 1963.
84. Advanced Research Inc.- "Prof. Guide on Reducing Vulnerability of Industrial Plants to the Effects of Nuclear Weapons" Office of Civil Defense- PSD-PG-8 1964.
85. Bridges, J.E. and Weyer- "EMP Threat and Countermeasures for Civil Defense" Illinois Institute of Technology- OCD Contract DAHC 20-68-c-0198- Nov. 1968.
86. Editors of McGraw Hill Publishing Co.- "Nuclear Attack and Industrial Survival" A McGraw Hill Special Report- 1962.
87. Office of Civil Defense- "Shelter Design and Analysis- Vol 1-" Tr-20- June 1968.
88. Office of Civil Defense- "Civil Defense Aspects of Waterworks Operations" Dept. of Defense- FG-F3-6- June 1966.
89. Staff College OCD- "Civil Defense USA" Unit 2- Dept. of Defense- Office of Civil Defense- SM5.2- June 1968.
90. Office of Civil Defense- "Blast Damage from Nuclear Weapons of Large Sizes" Technical Bulletin Tr-8-1- Feb 1955. (Out of Print) and Department of Commerce "Facility Protection for Food Processing Plants" FG-F-3.54 USGPO-0-404-276 1970
91. Walker, F.E.- "Estimating Production and Repair Effort in Blast-Damaged Petroleum Refineries" Stanford Research Institute- July 1969.
92. Dept. of Commerce- "Iron and Steel Industrial Defense Planning Manual" In cooperation with Office of Civil Defense- Oct. 1965.
93. Office of Civil Defense- "Fallout Shelter in Industrial Commercial and Business Buildings" April, 1966.
94. Office of Civil Defense- "Fallout Shelters" Codes and Standards TR-39- Dec., 1969.
95. Office of Emergency Planning- "The National Plan for Emergency Preparedness" (Supt. of Documents 75¢)- December, 1964.
96. Staff College, Office of Civil Defense- "Civil Defense, USA" Unit 5- Dept. of Defense, OCD SM5.5- June 1968.
97. Office of Civil Defense- "Industrial Civil Defense-Federal Civil Defense Guide" Part F- Chapter 3- OCD- August, 1966.
98. Emergency Advisory Committee for Natural Gas- "Emergency Operations Guide for the Natural Gas Transmission and Distribution Industry" U.S. Dept. of Interior- Office of Oil and Gas- October, 1967.
99. National Petroleum Council- "What is the Emergency Petroleum and Gas Administration "Dept. of Interior request. Reprinted by Civil Defense- (Free on request).
100. National Petroleum Council- "Civil Defense Planning for the Petroleum and Natural Gas Industries" Vol. I and II- Dept. of Interior request- Reprint OCD- March 19, 1964.
101. Department of Commerce- "Preparedness in the Chemical and Allied Industries" In cooperation with the Department of Defense- OCD- 1968- (Supt. of Doc. 45¢).
102. Am. Soc of Corp. Sec. Inc.- "Continuity of Corporate Management in Event of Nuclear Attack" Office of Civil Defense- A Study Done At the request of Virgil Couch, OCD- 1963.
103. Dept. of Defense- "A Guide to Developing a Company Industrial Civil Defense Manual" Office of Civil Defense- FG-F-3.8- April, 1969. (See local Civil Defense director).
104. Department of Defense- "Industrial Civil Defense Workbook" Office of Civil Defense- FG-F3.3- 1966. (See local Civil Defense director)
105. Office of Secretary of Defense- "Industrial Emergency Plan Outline" Defense Industry Bulletin- p. 21- July, 1968.
106. National Association of Manufacturers- "A Check List for Plant Security" Cooperative publication with the Department of the Army- May, 1968.
107. Department of Defense- "Federal Civil Defense Guide" Part 6,- Chapter 1- app. 1- Office of Civil Defense- Nov., 1967.
108. Addington, Lloyd B.- "Postattack Viability of the United States- 1975" Office of Army Engineers- National Academy of Sciences, etal. "Symposium on Postattack Recovery from Nuclear War" Nov. 6-9, 1967.
109. Minvielle, L. and Van Horn, Wm.- "Recovery of Petroleum Refinery Contaminated by Fallout" U.S. Naval Radiological Defense Laboratory- USNROL-TR-656- Project sponsored by the Office of Civil Defense- 24 June, 1963.
110. Healy, Richard, J.- "Design for Security" Aerospace Corp.- John Wiley & Sons, Inc.- Feb., 1968.
111. Healy, Richard J.- "Emergency and Disaster Planning" John Wiley & Sons, Inc.- March, 1969.

Appendix

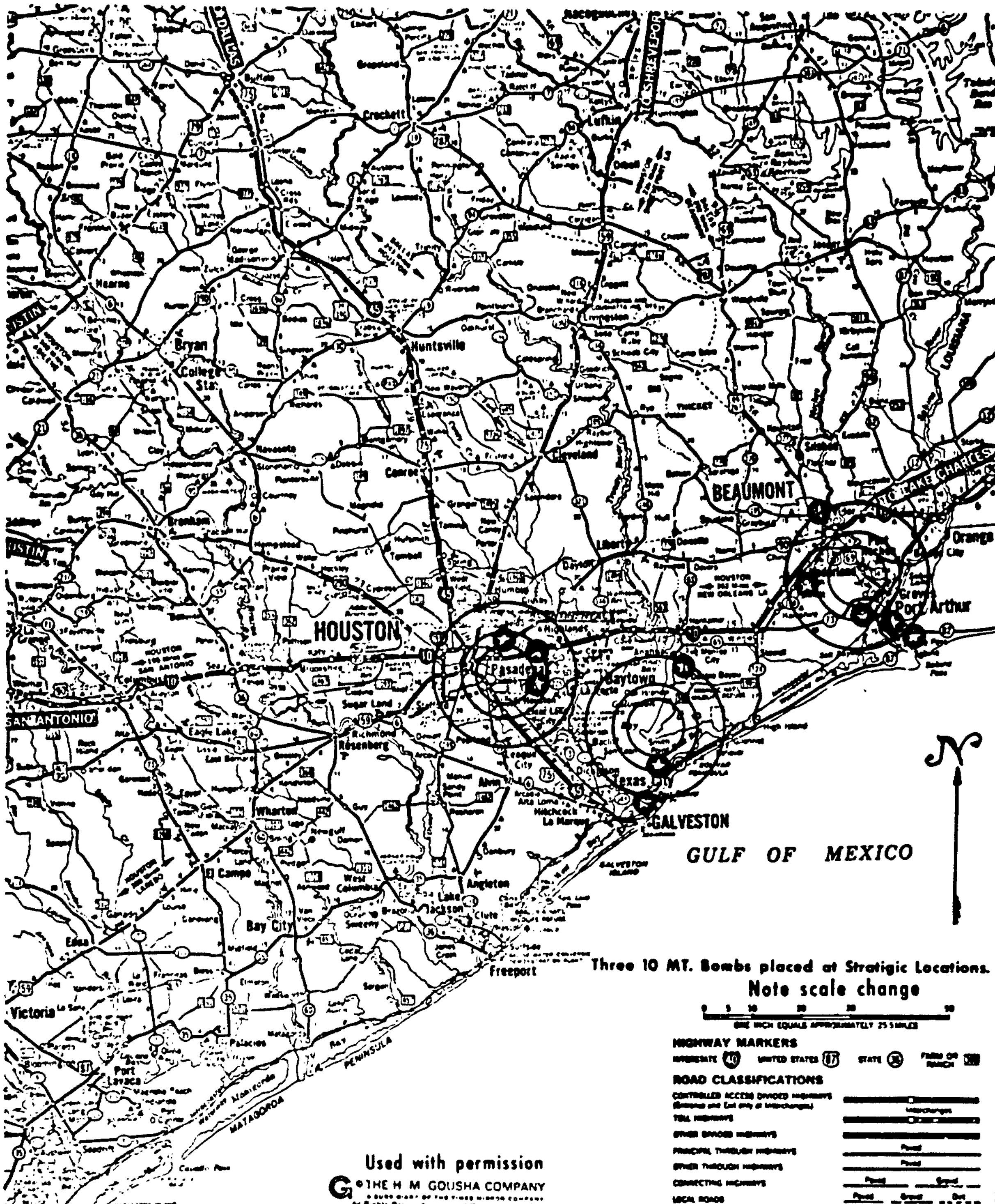


Preceding page blank


PHILADELPHIA
PHILADELPHIA AND VICINITY
Marcus Hook
Courtesy Hertz Rent a Car Used with permission
Large refineries

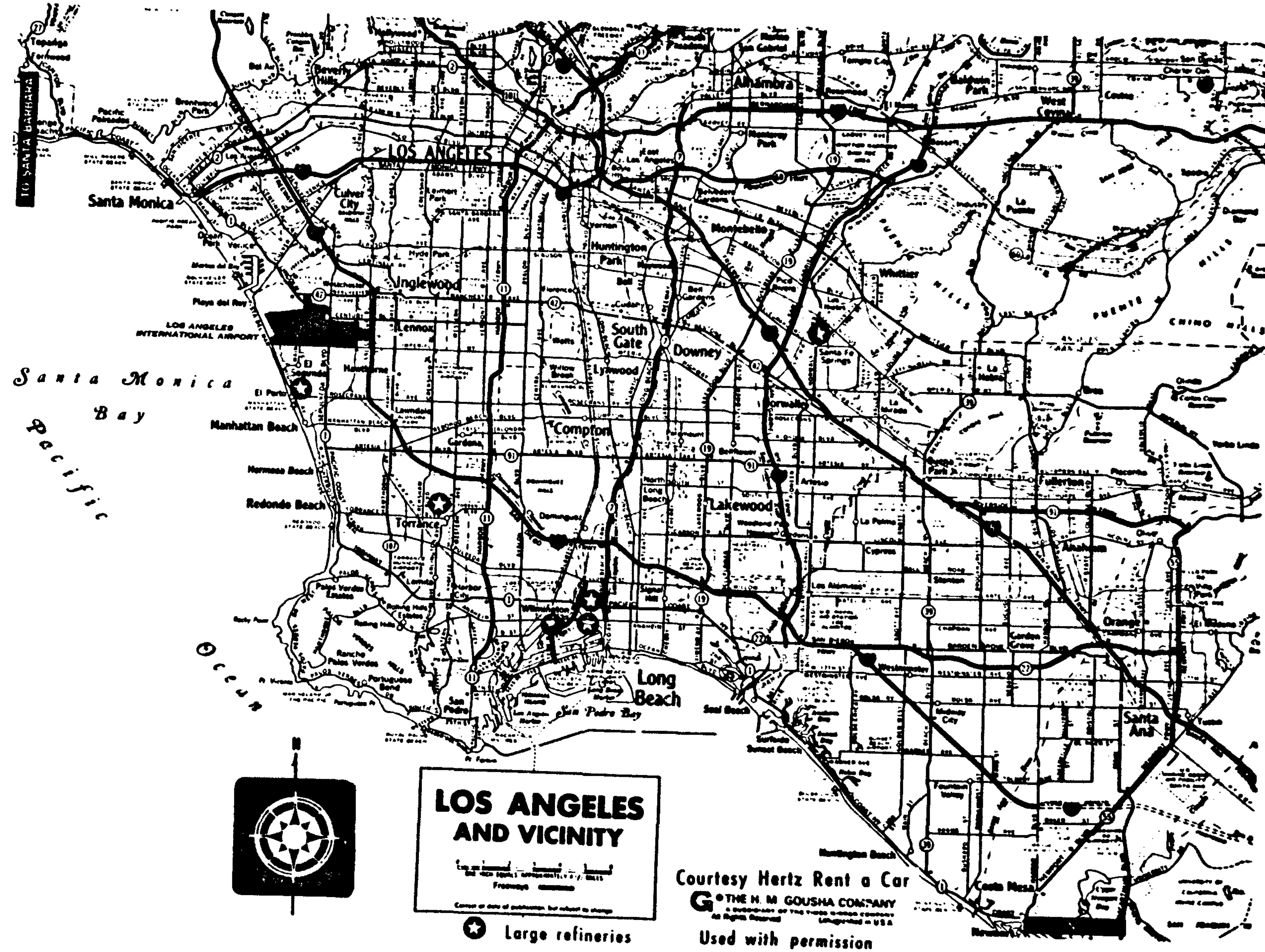

Large refineries
Whiting
E.Chicago
Hammond
I G A N
CHICAGO AND VICINITY
Courtesy Hertz Rent a Car
Used with permission

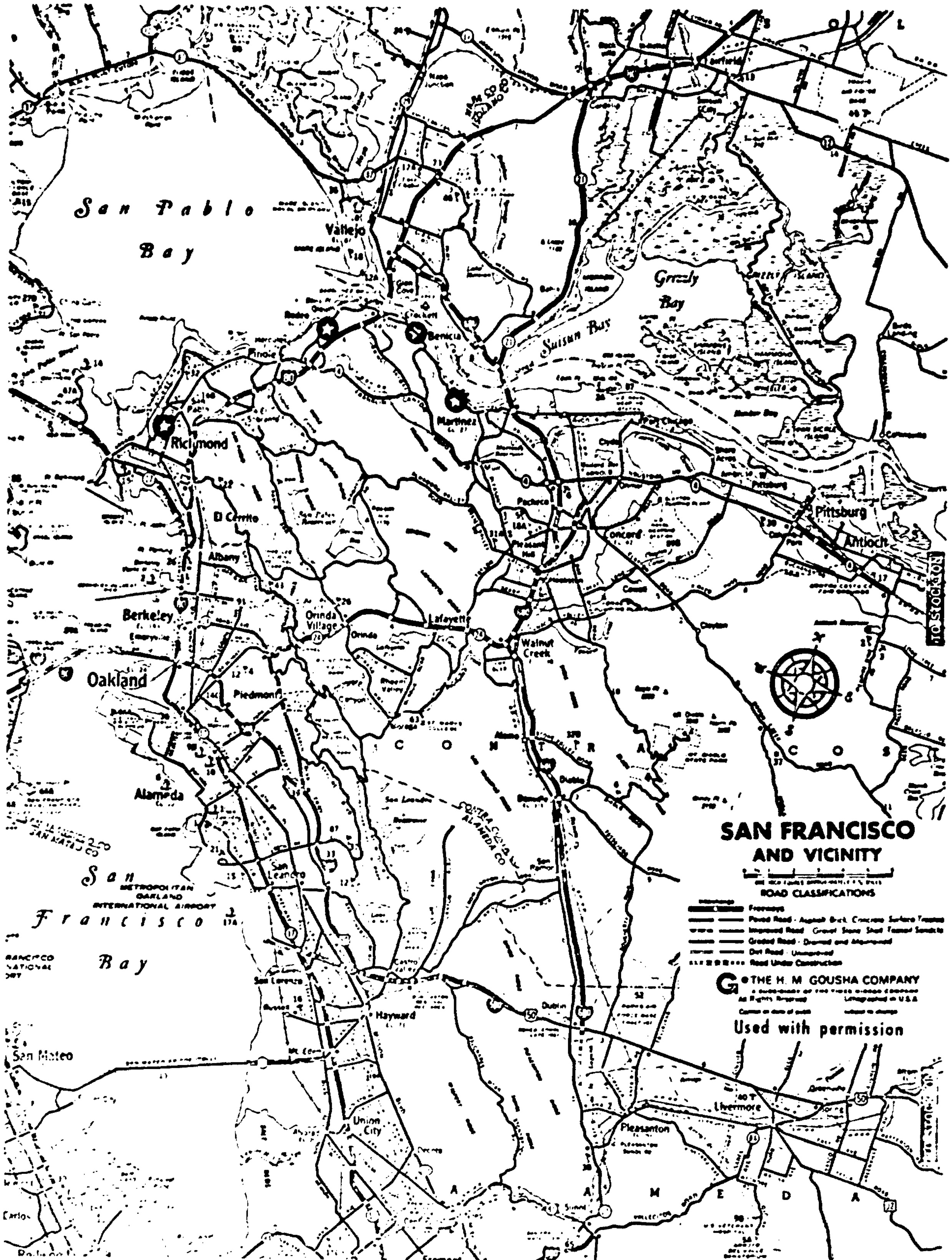
Large refineries   Courtesy Hertz Rent a Car   Used with with permission



Courtesy Hertz Rent a Car

Large refineries


LOS ANGELES
AND VICINITY
Large refineries
Courtesy Hertz Rent a Car
THE H. M. GOUSHA COMPANY
Used with permission
TO SANTA BARBARA
Santa Monica Bay
Pacific Ocean
San Pedro Bay
Los Angeles International Airport
Santa Monica
Beverly Hills
Culver City
Inglewood
Lennox
Hawthorne
El Segundo
Manhattan Beach
Hermosa Beach
Redondo Beach
Torrance
Gardena
Compton
Lynwood
South Gate
Huntington Park
Downey
Montebello
Alhambra
Monterey Park
West Covina
Baldwin Park
Whittier
Norwalk
Lakewood
Long Beach
Seal Beach
Fullerton
Anaheim
Orange
Garden Grove
Westminster
Santa Ana
Costa Mesa
Huntington Beach
Palos Verdes Estates
San Pedro
Wilmington
Signal Hill
Bellflower
Artesia
La Palma
Cypress
Stanton
Buena Park
La Habra
Brea
Santa Fe Springs
Puente Hills
Chino Hills



Large Refineries

Courtesy Hertz Rent a Car

The following tables estimate the amount of repair material required to replace various refinery units. For more detail refer to the reference cited.

Table 15. Critical Materials Requirements for Petroleum Refining

Crude Distillation
(including desalting, vacuum and stabilization)

Tabulation of Material Requirements)

Crude Charge	Unit Capacity B/SD 10,000	75,000	150,000
I. Copper			
A. Wire and cable (in feet)			
1. 600V, Single conductor (Size)			
12	70,000	88,000	100,000
10	25,000	40,000	60,000
8	10,000	20,000	50,000
6	3,000	5,000	7,000
4	5,000	8,000	15,000
2	4,000	10,000	18,000
1/0	500	800	1,000
2/0	2,000	3,000	4,000
3/0	1,000	1,800	2,000
4/0	2,000	3,500	4,000
250 MCM	2,000	5,000	6,000
300 MCM	800	1,500	2,000
350 MCM	1,500	2,700	3,000
500 MCM	–	–	100
2. 5 KV, Single conductor (Size)			
4	1,200	2,000	2,500
2	2,000	3,000	3,500
1	–	–	–
1/0	–	–	–
2/0	–	–	2,200
3/0	1,000	1,400	–
4/0	–	–	–
250 MCM	–	–	800
3. 12 KV, 3 conductor (Size)			
1/0	500	800	–
2/0	–	–	200
4/0	–	–	1,200
B. Other (in tons)	12	15	20
II. Aluminum (in tons)	15	40	70

Table 15. Critical Materials Requirements for Petroleum Refining (Continued)

		Unit Capacity B/SD	
Crude Charge	10,000	75,000	150,000
III. Pumps, Compressors, etc. (number of units)			
A. Pumps and Motors (HP)			
0-20	19	7	13
21-100	14	10	9
125	–	1	3
150	–	1	1
200	–	5	2
250	–	1	1
350	–	2	1
400	–	–	1
B. Pumps and Turbines (HP)			
500	–	2	–
600	–	–	1
1,200	–	–	1
C. Miscellaneous Drivers (HP) Fans and Motors			
0-20	22	14	26
21-100	–	14	22
IV. Electrical (number and type)			
A. Transformers			
13,800/480V	1-1,000KVA	3-1,000KVA	4-1,000KVA
13,000/4160V	–	1-1,500KVA	1-3,750KVA
480/120V	1-10KVA	2-30KVA	3-30KVA
B. Switchgear (cubicles)			
13,800V	–	4	6
C. Motor Control centers			
480V	1	3	4
V. Instrumentation (number)			
A. Temperature Transmitters	9	12	15
B. Pressure Indicators	17	21	23
C. Flow Transmitters	55	70	74
D. Level Instruments	15	15	15
E. Local Controllers	13	17	21
F. Temperature Elements	200	250	300
G. Pressure Elements	125	150	175
H. Flow Elements	12	12	12
I. Level Gauges	30	30	30
J. Solenoid Valves	10	13	15
K. Control Valves	60(1½-3")	80(2-6")	90(3-10")
L. Relief Valves	5	8	8
M. Multipoint Temperature Recorders	2	4	4
N. Receiver Controllers	55	80	85

Table 15. Critical Materials Requirements for Petroleum Refining (Continued)

Crude Charge	Unit Capacity B/SD 10,000	75,000	150,000
O. Receiver Records	40	50	55
P. Receiver Indicators	5	8	9
Q. Alarm Switches	20	30	40

Tabulation of Utility Requirements

Crude Charge	Unit Capacity B/SD 10,000	75,000	150,000
1. Electricity (KVA)	465	3,500	7,000
2. Fuel Gas (SCFH)	52,000	390,000	780,000
3. Cooling Water (GPM)	670	5,000	10,000
4. Steam (lbs./hour)	9,600	72,000	144,000
5. Air (CFM)			
(a) Instrument air	100	200	300
(b) Plant air	200	400	500

Table 16. Catalytic Reforming and Feed Preparation

Tabulation of Material Requirements

	Unit Capacity B/SD		
Fresh Feed	5,000	20,000	40,000
I. Copper			
A. Wire and cable (in feet)			
1. 600V, Single conductor (Size)			
12	50,000	80,000	90,000
10	15,000	25,000	28,000
8	6,000	10,000	13,000
6	2,000	2,500	3,000
4	3,000	4,000	5,000
2. 600V, Single conductor (Size cont'd.)			
2	3,500	5,000	6,000
1/0	3,000	4,000	4,500
2/0	2,000	2,500	3,000
3/0	1,000	1,200	1,500
4/0	800	1,500	1,500
250 MCM	1,800	2,300	2,300
300 MCM	500	500	500
400 MCM	1,000	1,300	1,300
3. 5KV, Single Conductor (Size)			
4	1,000	1,200	1,200
1	1,000	1,200	1,200
3/0	1,000	1,200	1,200
4. 15KV 3 conductor (Size)			
350 MCM	500	1,000	1,000
II. Pumps, Compressors, etc. (number of units)			
A. Pumps and Motors (HP)			
0-20	9	8	10
21-100	9	9	8
125-200	2	5	4
250-500	1	2	4
B. Compressors and drivers (HP)			
1. Turbines			
2,000-3,000	1	–	–
3,000-3,500	–	1	1
III. Electrical (number and type)			
A. Transformers			
13,800/4,160V	–	–	1-3,500KVA
13,800/2,400V	1-2,000KVA	1-3,000KVA	–
4,160/480V	1-1,500KVA	1-1,500KVA	1-1,500KVA
480/240V	2-100KVA	3-100KVA	4-100KVA

Table 16. Catalytic Reforming and Feed Preparation (Continued)

	Unit Capacity B/SD		
Fresh Feed	5,000	20,000	40,000
III. Electrical, cont'd. (number and type)			
B. Switchgear			
2,400V	1	–	–
4,160V	–	1	1
C. Motor control centers	1	2	3
D. Instrumentation (number)			
1. Temperature elements	75	130	170
2. Pressure elements	100	370	480
3. Flow elements	34	43	60
4. Level instruments	16	28	35
5. Temperature transmitters	4	9	12
6. Flow transmitters	30	40	60
7. Pressure controllers	4	7	10
8. Local controllers	4	4	6
9. Controllers	53	68	90
10. Multipoint temperature recorders	3	6	8
11. Recorders	4	4	6
12. Indicators	4	4	6
13. Alarm switches	16	20	30
14. Level gauges	18	31	55
15. Control valves	40	55	75
16. Solenoid valves	2	4	6
17. Pressure relief valves	20	38	50

Tabulation of Utility Requirements

1. Electricity (EVA)	1,400	2,300	2,800
2. Fuel gas (SCFH)	85,000	310,000	610,000
3. Cooling water (GPM)	2,600	9,900	19,200
4. Steam (lbs./hour)	2,300	8,000	15,500
5. Air (CFM)			
a. Instrument air	90	120	150
b. Plant air	800	800	800

Tabulation of Initial Fill Catalysts

1. Hydrotreater- catalyst required			
a. Type; Cobalt-Molybdenum (cubic feet)	410	1,860	3,400
2. Catalytic reformer- catalyst required			
a. Type; Platinum (cubic feet)	575	2,550	4,800

Table 17. Catalytic Cracking

Tabulation of Material Requirements

	Unit Capacity B/SD		
Fresh Feed	10,000	35,000	60,000
I. Copper			
A. Wire and cable (in feet)			
1. 600V, Single conductor (Size)			
12	75,800	66,200	65,200
10	3,600	1,200	–
8	12,000	1,200	2,400
6	12,000	1,200	–
4	10,800	–	–
3	–	2,400	–
2	7,200	–	2,400
0	4,800	10,800	2,400
3/0	8,750	3,600	4,000
4/0	–	9,600	6,000
300 MCM	–	2,400	8,400
2. 6KV, Single conductor (Size)			
8	–	9,600	10,800
6	–	4,800	6,000
4	–	–	–
2	–	–	9,600
3. Instrument control cable			
a. No. 20 multiconductor control cable (single wire)	200,000	200,000	200,000
b. Thermocouple lead wire-1/C	30,000	30,000	30,000
B. Other (in tons)	54	100	145
II. Pumps, Compressors, etc. (number of units)			
A. Pumps and motors (HP)			
0-20	10	4	3
21-100	20	11	4
125	–	5	3
150	–	2	4
200	–	2	6
250	–	2	1
300	–	2	3
350	–	2	–
500	–	–	6
B. Compressors and drivers (HP)			
1. Condensing turbines			
a. Air blower	4,150	14,500	24,500
b. Wet gas compressor	2,110	7,500	12,500
III. Electrical (number and type)			
A. Transformers (3)			
13,800/4,160V	–	1-1,500KVA	1-5,000KVA
13,800/480V	1-1,000KVA	1-1,500KVA	1-1,500KVA
4,160/120V	1-150KVA	1-150KVA	1-150KVA

Table 17. Catalytic Cracking (Continued)

Fresh Feed	Unit Capacity B/SD 10,000	35,000	60,000
III. Electrical (number and type), cont'd.			
B. Switchgear (cubicles)	2	3	3
C. Motor control centers	1	2	2
IV. Instrumentation			
A. Temperature transmitters	10	10	10
B. Pressure indicators	120	120	120
C. Flow transmitters	35	35	35
D. Level instruments	33	33	33
E. Local controllers	10	10	10
F. Temperature elements, thermocouple	70	70	70
G. Pressure elements	20	20	20
H. Flow elements	45	45	45
I. Level gauges	50	50	50
J. Control valves 1-1/2" to 3"	72	60	30
K. Control valves 4" to 6"	3	10	25
L. Control valves 8" and over	—	5	20
M. Relief valves	35	35	35
N. Multipoint temperature recorders	2	2	2
O. Receiver controllers	69	69	69
P. Receiver recorders	22	22	22
Q. Receiver indicators	7	7	7
R. Alarm switches	1 panel	1 panel	1 panel
S. Transducers MV/air	100	100	100
T. Flow indicators	10	10	10
U. Thermometers	40	40	40

Tabulation of Utility Requirements

1. Electricity (KVA)	1,020	2,950	5,060
2. Cooling water (GPM)	11,520	40,300	68,750
3. Steam (lbs./hour)	112,100	393,000	690,000
4. Air (CFM)			
a. Instrument air	150	150	150
b. Plant air	200	200	200

Tabulation of Initial Fill Catalysts

1. Equilibrium Catalyst (in tons) (for plant fill)	90	310	540
2. New Catalyst (in tons) (for inventory)	200	700	1,200

Table 18. Direct Fired, Fresh Feed Heater for Catalytic Cracking

Tabulation for Material Requirements

Fresh Feed	Unit Capacity B/SD 10,000	35,000	60,000
I. Copper			
A. Wire and cable (in feet)			
Instrument control cable			
1. No. 20 multiconductor control cable (single wire)	1,600	3,600	6,000
II. Instrumentation (number)			
A. Temperature transmitters	3	4	6
B. Flow transmitters	1	2	4
C. Temperature elements	3	4	6
D. Flow elements	1	2	4
E. Control valves 1-1/2" to 3"	1	2	4
F. Control valves 4' to 6"	—	1	1
G. Relief valves	1	2	2
H. Multipoint temperature recorders	1	1	1
I. Receiver controllers	2	3	5
J. Receiver recorders	—	1	3
K. Alarm switches	1 panel	1 panel	1 panel

Tabulation of Utility Requirements

Fresh Feed	10,000	35,000	60,000
1. Fuel gas (SCFH)	43,000	150,000	260,000

Table 19. CO Boiler for Catalytic Cracking

Tabulation of Material Requirements

	Unit Capacity B/SD		
Fresh Feed	10,000	35,000	60,000
I. Copper			
A. Wire and cable (in feet)			
a. 600V, Single conductor (Size)			
12	1,200	1,200	1,200
2	1,200	–	–
b. 6KV, Single conductor (Size)			
8	–	1,200	–
6	–	–	1,200
II. Pumps, Compressors, etc. (number of units)			
A. Pumps and motors (HP)			
21-100	1	–	–
200	–	1	–
300	–	–	1
B. Miscellaneous drivers (HP)			
a. Forced draft fan			
21-100	1	–	–
175	–	1	–
300	–	–	1
III. Electrical (number and type) (capacity included in catalytic cracking unit)			
IV. Instrumentation (number)			
A. Pressure indicators	2	2	2
B. Flow transmitters	5	5	5
C. Level instruments	1	1	1
D. Pressure elements	4	4	4
E. Flow elements	5	5	5
F. Level gauges	2	2	2
G. Control valves	3	3	3
H. Relief valves	2	3	3
I. Receiver controllers	3	3	3
J. Receiver recorders	12	12	12
K. Receiver indicators	2	2	2
L. Alarm switches	1 panel	1 panel	1 panel
M. Flameguards	1	1	1

Tabulation of Utility Requirements

	10,000	35,000	60,000
1. Electricity (KVA)	53	155	265
2. Fuel gas (SCFH)	5,000	15,000	25,000
3. Boiler feed water (GPM)	90	300	540

Table 20. Delayed Coking

Tabulation of Material Requirements

	Unit Capacity B/SD		
Fresh Feed	5,000	20,000	35,000
Coke (tons/sd)	365	1,460	2,560
I. Copper			
A. Wire and cable (in feet)			
1. 600V, Single conductor			
(Size)			
12	40,000	70,000	100,000
10	15,000	25,000	40,000
8	6,000	10,000	17,500
6	1,500	1,200	2,500
4	4,000	3,000	6,000
2	1,500	3,500	4,000
1/0	2,000	4,000	10,000
2/0	2,000	3,000	4,000
3/0	1,500	2,000	3,000
4/0	800	1,200	1,500
250 MCM	2,000	4,000	6,000
350 MCM	–	–	2,000
400 MCM	2,250	2,700	3,600
2. 5 KV, Single conductor			
(Size)			
4	–	1,000	2,000
3/0	–	800	–
3. 15KV, 3 conductor			
(Size)			
350 MCM	600	800	1,000
B. Other (in tons)	11	36	58
II. Aluminum (in tons)	4	12	24
III. Pumps, Compressors, etc. (number of units)			
A. Pumps and Motors (HP)			
0-20	12	8	8
21-100	13	12	17
125	–	–	–
150	–	1	–
200	–	–	–
250	–	1	2
300	–	–	1
400	–	2	3
B. Pumps and turbines (HP)			
1. Condensing turbine			
1,100	1	1	2
IV. Electrical (number and type)			
A. Transformers			
13,800/4,160V	–	1-2,000KVA	1-3,750KVA
13,800/480V	1-750KVA	–	–

Table 20. Delayed Coking (Continued)

	Unit Capacity B/SD		
Fresh Feed	5,000	20,000	35,000
Coke (tons/sd)	365	1,460	2,560
IV. Electrical (number and type), cont'd.			
A. Transformers, cont'd.			
13,800/120V	1-45KVA	–	–
4,160/480V	–	1-750KVA	2-750KVA
4,160/120V	–	1-75KVA	1-112.5KVA
B. Switchgear (See Pumps and motors Item III-A above)			
C. Motor Control centers			
8 vertical units	1	1	1
4 vertical units	–	–	1
D. Cubicles			
4,160V	–	7	10
V. Instrumentation			
A. Temperature elements	120	160	280
B. Pressure elements	103	131	159
C. Flow elements	69	90	112
D. Level instruments	15	15	15
E. Level gauges	15	15	15
F. Temperature transmitters	12	24	36
G. Pressure transmitters	13	21	29
H. Flow transmitters	38	50	62
I. Local controllers	4	4	4
J. Receiver controllers	36	48	60
K. Receiver recorders	36	56	73
L. Receiver indicators	36	46	56
M. Multipoint temperature recorders	2	3	5
N. Alarms	22	30	38
O. Solenoid valves	8	10	12
P. Control valves	48 (2-4")	60 (2-8")	72 (2-10")
Q. Relief valves	11	21	31
R. Thermal relief valves	15	15	15
S. Gamma ray level	2	6	10

Tabulation of Utility Requirements

1. Electricity (KVA)	617	1,625	3,212
2. Fuel gas (SCFH)	75,000	220,000	375,000
3. Cooling water (GPM)	2,500	6,000	11,000
4. Boiler feed water (GPM)	35	105	175
5. Steam (lbs./hour)			
a. Steam demand	15,000	35,000	65,000
b. Steam generated in unit	15,000	45,000	75,000
c. Net steam produced	–	10,000	10,000
6. Air (CFM) Instrument air (65 psig)	100	160	200
Plant air (100 psig)	1,500	2,000	4,000

Table 21. Hydrotreating

Tabulation of Material Requirements

	Unit Capacity B/SD		
Fresh Feed	5,000	20,000	40,000
I. Copper			
A. Wire and cable (in feet)			
1. 600V, Single conductor (Size)			
12	15,000	20,000	20,000
10	4,000	6,000	6,000
8	1,500	2,000	3,000
6	500	800	800
4	1,000	1,000	1,500
2	1,000	1,000	2,000
1/0	800	1,200	1,200
2/0	500	500	500
3/0	300	300	300
4/0	200	300	500
300 MCM	500	500	500
2. 5KV, Single conductor (Size)			
4	500	500	500
3/0	1,000	1,000	1,200
B. Other (in tons)			
1. Admiralty metal tubing	9	25	35
II. Pumps, Compressors, etc.			
A. Pumps and Motors (HP)			
0-20	2	2	2
21-100	3	3	2
125-200	–	2	2
250-500	–	–	2
B. Compressors and drivers (HP)			
1. Turbines			
2,500-3,000	1	–	–
3,000-3,500	–	1	1
III. Electrical (number and type)			
A. Transformers			
13,800/2,400V	–	–	1-1,000KVA
13,800/480V	1-750KVA	1-1,000KVA	1-1,000KVA
480/240V	2-50KVA	3-50KVA	2-100KVA
B. Switchgear			
480V	1	1	1
C. Motor Control centers	1	1	2
IV. Instrumentation (number)			
A. Temperature elements	25	50	65
B. Pressure elements	30	120	160
C. Flow elements	14	14	18
D. Level instruments	8	10	10
E. Temperature transmitters	2	3	4

Table 21. Hydrotreating (Continued)

Fresh Feed	Unit Capacity B/SD 5,000	20,000	40,000
IV. Instrumentation (number), cont'd.			
F. Flow transmitters	10	12	20
G. Pressure controllers	2	3	3
H. Local controllers	1	1	2
I. Controllers	15	18	18
J. Multipoint temperature recorders	1	1	1
K. Recorders	1	1	1
L. Indicators	1	1	2
M. Control valves	16	18	18
N. Pressure relief valves	13	16	16

Tabulation of Utility Requirements

	5,000	20,000	40,000
1. Electricity (KVA)	400	750	1,500
2. Fuel gas (SCFH)	30,000	105,000	200,000
3. Cooling water (GPM)	1,300	4,500	9,500
4. Steam (lbs./hour)	800	3,000	5,000
5. Air (CFM)			
(a) Instrument air	35	35	35
(b) Plant air	500	500	500

Table 22. Hydrocracking

Tabulation of Material Requirements

	Unit Capacity B/SD		
Fresh Feed	10,000	20,000	40,000
I. Copper			
A. Wire and cable (in feet)			
1. 600V, Single conductor (Size)			
14	41,000	90,000	162,000
12	22,000	40,300	72,000
10	18,000	34,000	64,000
8	9,000	16,000	29,000
6	13,000	23,500	39,000
2	7,000	12,000	21,000
1	750	1,500	2,700
2/0	6,000	9,000	15,500
3/0	1,000	1,000	1,600
4/0	2,500	4,000	7,600
350 MCM	2,000	2,000	3,300
500 MCM	–	600	1,000
750 MCM	–	200	300
2. 2,400V feeders (Size)			
2	300	500	700
1/0	200	200	400
500 MCM	500	700	1,000
3. 15KV cable (Size)			
0/0	1,000	3,000	5,000
750 MCM	1,000	2,000	3,000
B. Other (in tons)	52	98	163
II. Aluminum (in tons) Conduit, fittings and miscellaneous (no electrical conductors)	6	12	20
III. Pumps, Compressors, etc. (number of units)			
A. Pumps and Motors (HP)			
0-20	4	3	1
21-100	5	7	8
101-500	4	7	10
B. Pumps and turbines (HP)			
1,500	2	3	–
3,000	–	–	3
C. Compressors and drivers (HP)			
1. Recycle gas compressor turbine	2-700HP 2-2,500HP	1-2,500HP 3-3,000HP	1-5,000HP 1-9,000HP
2. Hydrogen make-up and booster compressor turbine	2-700HP	3-1,000HP	3-2,000HP
D. Miscellaneous dribers (HP)			
1. Fans and motors			
0-20	12	8	–
21-100	12	16	24

Table 22. Hydrocracking (Continued)

Fresh Feed	Unit Capacity B/SD 10,000	20,000	40,000
IV. Electrical (number and type)			
A. Transformers			
13,800/2,400V	1-6,000KVA	1-12,000KVA	2-12,000KVA
13,800/480V	1-1,500KVA	1-3,000KVA	1-6,000KVA
B. Switchgear			
480V	2	2	2
2,400V	1	1	1
C. Motor control centers			
480V	2	2	2
2,400V	2	2	2
V. Instrumentation (number)			
A. Temperature elements	132	198	426
B. Temperature indicators	24	36	92
C. Control valves and positioners	48	72	156
D. Alarms	34	51	112
E. Level gauges	13	18	24
F. Pressure indicators	96	128	164
G. Field transmitters	66	96	184
H. Field indicators, recorders and controllers	34	42	52
I. Control panel instruments	51	76	163

Tabulation of Utility Requirements

1. Electricity (KVA)	3,000	6,000	10,000
2. Fuel gas (SCFH)	200,000	300,000	600,000
3. Cooling water (GPM)	8,500	17,000	25,500
4. Steam (lbs/hour)	78,000	130,000	208,000
5. Air (CFM)			
(a). Instrument air	85	125	200
(b). Plant air	250	300	400

Table 23. Hydrogen Plant

Tabulation of Material Requirements

	Unit Capacity M SCFD		
Hydrogen Produced	10,000	40,000	60,000
I. Copper			
A. Wire and cable (in feet)			
1. 600V, single conductor			
(Size)			
14	13,000	18,000	23,000
12	3,000	4,100	6,200
10	300	400	600
8	1,500	2,000	3,000
6	6,000	8,000	10,000
4	1,000	1,200	1,800
2	1,000	2,000	3,800
1/0	1,200	3,000	4,800
3/0	1,000	1,200	1,200
350 MCM	600	1,000	1,500
2. 2,400 V feeders			
(Size)			
1	2,000	2,400	3,200
300 MCM	1,200	1,800	2,300
350 MCM	1,200	1,800	2,400
3. 15KV cable			
(Size)			
500 MCM	2,200	3,200	4,000
B. Other (in tons)	9	12	15
II. Aluminum (in tons)	2	4	6
III. Pumps, Compressors, etc. (number of units)			
A. Pumps and Motors (HP)			
0-20	4	3	3
21-100	3	5	5
101-400	3	4	4
B. Compressors and drivers (HP)			
Motors			
21-100	1	1	1
C. Miscellaneous fans and motors			
0-20	2	–	–
21-100	–	2	2
IV. Electrical (number and type)			
A. Transformers			
13,800/2,400V	2-1,000KVA	2-2,500KVA	2-3,000KVA
13,800/480V	2-1,000KVA	2-2,000KVA	2-4,000KVA
B. Switchgear			
480V	1	1	1
2,400V	1	1	1
C. Motor control centers			
480V	4	6	8

Table 23. Hydrogen Plant (Continued)

	Unit Capacity M SCFD		
Hydrogen Produced	10,000	40,000	60,000
V. Instrumentation (number)			
A. Temperature elements	38	62	85
B. Temperature indicators	15	28	42
C. Control valves and positioners	40	60	80
D. Alarms	30	35	42
E. Level Gauges	12	15	22
F. Pressure indicators	47	60	78
G. Field transmitters	57	72	86
H. Field indicators, recorders and controllers	22	38	55
I. Control panel instruments	42	58	72
Tabulation of Utility Requirements			
1. Electricity (KVA)	250	850	1,150
2. Fuel gas (SCFH)	100,000	400,000	600,000
3. Cooling water (GPM)	3,000	12,000	18,000
4. Boiler feed water (GPM)	70	280	420
5. Steam (lbs./hour)			
Net steam produced	7,000	18,000	26,000
6. Air (CFM)			
(a) Instrument air	30	90	120
(b) Plant air	120	300	400
Tabulation of Initial Fill Catalysts			
1. Reformer (cubic feet)	300	1,200	1,800
2. Shift converter (cubic feet)	1,000	4,000	6,000
3. Methanator (cubic feet)	250	1,000	1,500

Table 24. Alkylation

	Unit Capacity B/SD		
Aviation Alkylate Production	1,000	3,500	6,000
Olefin Feed	590	2,060	3,530
I. Copper			
A. Wire and cable (in feet)			
1. 600V, Single conductor (Size)			
12	20,000	20,000	15,000
8	600	12,000	12,000
4	4,500	5,000	–
600 MCM	–	1,200	2,400
2. 5KV, Single conductor (Size)			
6	–	–	1,200
B. Other (in tons)	1.0	1.8	2.0
II. Pumps, Compressors, etc. (number of units)			
A. Pumps and motors (HP)			
0-20	34	34	25
21-100	2	5	6
400	–	–	1
B. Compressors and drivers (HP)			
800	1	–	–
1,250	–	1	–
1,500	–	–	1
1,750	–	1	–
2,750	–	–	1
C. Miscellaneous drivers (HP)			
1. Mixers and motors			
21-100	7	10	18
III. Electrical (number and type)			
A. Transformers			
13,800/480V	2-750KVA	2-1,200KVA	1-1,500KVA
13,800/2,400V	–	–	1-1,500KVA
480/120V	2-15KVA	2-15KVA	2-15KVA
B. Switchgear (cubicles)			
600V	5	5	5
5KV	–	–	2
C. Motor control centers			
600V	4	4	4
IV. Instrumentation			
A. Flow elements	25	35	45
B. Flow transmitters	40	43	45
C. Flow recorders	25	21	20
D. Flow recorder controllers	15	20	25
E. Temperature elements	50	55	60
F. Temperature indicators	50	55	60
G. Temperature recorder controllers	10	10	10
H. Pressure elements	75	80	85
I. Pressure indicators	75	80	85

Table 24. Alkylation (Continued)

	Unit Capacity B/SD		
Aviation Alkylate Production	1,000	3,500	6,000
Olefin Feed	590	2,060	3,530
IV. Instrumentation, cont'd.			
J. Pressure recorder controllers	15	16	17
K. Level instruments	15	18	20
L. Level recorder controllers	15	18	20
M. Level gauges	15	18	20
N. Control valves	55	63	72
O. Low and high level alarms	10	10	10
P. Alarm switches	20	20	20
Q. Multipoint temperature recorders	1	1	1
R. Relief valves	55	55	56

Tabulation of Utility Requirements

1. Electricity (KVA)	1,375	2,000	2,490
2. Cooling water (GPM)	3,000	5,500	8,000
3. Steam (lbs./hour)			
(a) Total 650 lb. steam	27,500	65,000	96,000
(b) 650 lb. steam to compressor (exhausting to process system)	27,500	65,000	91,500
(c) Process requirements (reboilers, etc.)	21,500	60,000	96,000
(d) Added requirements for process over that provided from turbine exhausts	(6,000)	(5,000)	4,500
4. Air (CFM)			
(a) Instrument air	158	190	205
(b) Plant air	200	200	200

Supplement

Heat Content of Various Solid and Liquid Fuels

Notes:

A. Data on hydroelectricity and electricity from nuclear power were furnished by the Federal Power Commission.

B. Import and export data for mineral fuels were compiled from data published by the Bureau of the Census.

C. Consumption data are calculated from production, minus exports (including shipments to noncontiguous territories), plus imports, plus or minus stock change: except for bituminous coal and lignite which represents actual consumption including a small amount consumed in noncontiguous territories.

D. Heat values used

1.	Bituminous coal	26,200,000 B.t.u./short ton
2.	Anthracite	25,400,000 B.t.u./short ton
3.	Crude petroleum	5,800,000 B.t.u./barrel
4.	Gasoline	5,248,000 B.t.u./barrel
5.	Kerosine	5,670,000 B.t.u./barrel
6.	Distillate fuel oil	5,825,000 B.t.u./barrel
7.	Residual fuel oil	6,287,000 B.t.u./barrel
8.	Lubricants	6,064,800 B.t.u./barrel
9.	Wax	5,537,280 B.t.u./barrel
10.	Asphalt	6,636,000 B.t.u./barrel
11.	Petroleum coke	6,024,000 B.t.u./barrel
12.	Miscellaneous	5,796,000 B.t.u./barrel

Natural gas wet.—For 1964 and prior years the gross production is multiplied by 1075 B.t.u. per cubic foot minus the volume of gas used for repressuring, vented, or flared multiplied by 1035 B.t.u. per cubic foot. The new basis consists of the dry natural gas production which excludes gas used for repressuring, vented, or flared multiplied by 1032 B.t.u. (1031 B.t.u. for 1969) per cubic foot to which is added the computed energy equivalent of the extraction loss based on the heat value of natural gas liquids production.

Natural gas dry.—For 1964 and prior years, the conversion factor used in 1035 B.t.u. per cubic foot. Data for 1965-68 is on the new basis converting at 1032 B.t.u. per cubic foot and for 1969 and 1970, 1031 cubic foot is used.

Natural gas liquids.—For 1964 and prior years, a weighted average B.t.u. based on production is used, derived by converting natural gasoline and cycle products at 110,000 B.t.u. per gallon and LP-gas, including ethane, at 95,500 B.t.u. per gallon. The new procedure differs by converting the ethana production separately at 73,390 B.t.u. per gallon.

Hydroelectricity and electricity from nuclear power.—Beginning with the 1964 data, hydro and nuclear power are converted to coal input equivalent at the prevailing average pounds of coal per kilowatt hour each year at central electric plants, using 12,000 B.t.u. per pound. Prior to 1964, 13,100 B.t.u. per pound was used.

☆U.S. GOVERNMENT PRINTING OFFICE: 1972 O–429-828